MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXX.

EDITED BY

JAMES FORREST, Assoc. Inst. C.E., Secretary.

LONDON:
Published by the Institution,
GREAT GEORGE STREET, WESTMINSTER, S.W.
[Telegrams, "Institution, London." Telephone, "3051."]
1895.

ADVERTISEMENT.

The Institution as a body is not responsible either for the statements made, or for the opinions expressed, in the following pages.

NOTICE.

To insure the punctual delivery of the Minutes of Proceedings, and of other communications from the Institution, it is essential that every change of address should be notified without delay to—

THE SECRETARY,
THE INSTITUTION OF CIVIL ENGINEERS,
Great George Street, Westminster, S.W.

LONDON: PRINTED BY WM. CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

CONTENTS.

SECT. I.—MINUTES OF PROCEEDINGS.

8, 15 and *22 January, 1895.*

29 January, 1895.

5 and *12 February, 1895.*

SECT. II.—OTHER SELECTED PAPERS.

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

THE INSTITUTION OF CIVIL ENGINEERS.

SESSION 1894-95.—PART II.

Sect. I.—MINUTES OF PROCEEDINGS.

8 January, 1895.

Sir DOUGLAS FOX, Vice-President, in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Member.

Fred Smith Button.
William Beedie Esson.
Benjamin James Forrest.
David Hay.
Robert Robertson, B.Sc.
Frank Edward Robinson.

And that the following Candidates had been admitted as

Students.

Hugh Daniel Badcock, B.A.
Henry Francis Brand.
Raymond Carpmael.
Harold Thomas Creasy.
Henry Herman Gordon, B.A.
William Cecil Gravely.
Thomas Hardie.
Louis John Hunt.
Francis Henry Hutton.
Bernard Courtney Laws.
John Blois Lutman.
Francis Edward Morgan.
Alfred Noël Neate.
William Frost Nuthall.
Lionel Langdon Paterson.
Richard Eagle Reeves.
Neville Roots.
William Campbell Shaw.
William Edward Trent.

The Candidates balloted for and duly elected were: as

Members.

Samuel George Homfray.
John Smith Raworth.
John Scarisbrick Walker.

Associate Members.

Miles Aspinall.
Edward Cecil Bartlett, Stud. Inst. C.E.
Thomas Burnside Crowther.
John Hubert Davies.
Henry Dearden.
Alfred Herbert Dykes, Stud. Inst. C.E.
Percy Tillson Gask, Stud. Inst. C.E.
Gustave Gillman.

Associate Members—continued.

Peter Gotto.
Follett Holt.
Robert Cattley Jackson.
George William Knowles.
John Alfred Leigh.
Henry Alexander Mavor.
George Thomas Murray.
Theodore Sergius Platts.
George Samuel Wyon Rogers, Stud Inst. C.E.
Richard Septimus Rounthwaite.
Daniel Rowe.
William Henry Savage.
William Curwen Sheard.
Thomas Ridsdill Smith.
Henry Edmund Stacey.
Frederick William Sutcliffe, Stud. Inst. C.E.
Edward Henry Tabor.
Francis Thursfield.
Rennie Charles Augustus Twyford.
John William Witts.
Benjamin James Wolfenden, Stud. Inst. C.E.
Francis Houlton Wrench, Stud. Inst. C.E.

(*Paper No. 2768.*)

(*Abridged.*)

"The St. Gothard Mountain Railway and the Stanzerhorn Cable-Railway."[1]

By Sigvard Johnson Berg, Assoc. M. Inst. C.E.

In the variety of systems presented by its railways, Switzerland may be said to exceed almost all other countries. Especially is this so in regard to mountain railways, of which many fine examples are found there. First must be mentioned the St. Gothard line, with special reference to the northern and southern approaches to the great tunnel. The metre-gauge Landquart-Davos line is noteworthy as attaining the greatest elevation in Europe reached by lines worked on the principle of adhesion. Further, there are lines worked partly by adhesion and partly by rack-and-pinion, lines on different systems of rack-and-pinion, and a number of cable-railways. Tables Nos. 1 and 2, Appendix I, contain a list of lines in Switzerland which may be termed mountain railways, with particulars of some of their interesting features.

In laying out railways in mountainous districts, not only must the engineer keep in view cheap construction combined with due consideration for economical working, but must also pay attention to many dangers that are almost unknown in the lowlands. He must consider the destructive effect of violent freshets, sometimes carrying large masses of heavy material; the risks of

[1] The discussion upon this and the succeeding Papers was taken together.

landslips, which in many cases cannot be avoided, as well as those peculiar to treacherous loose formations which, though not tending to slip in great masses, are constantly crumbling away; and the dangers and hindrances caused by heavy snow-falls and by avalanches.

The difficulties caused by avalanches and the protective works necessary to guard against them are well worth mentioning, especially as the avalanche question has only of late years been systematically sifted. It has been calculated that on the St. Gothard mountain group alone, about 425 million cubic yards of snow are on an average annually set in motion through avalanches. These vary much in character, but may be roughly arranged in two classes, viz., ground avalanches and snow-dust avalanches. Both kinds are often very powerful, but the latter is the more dangerous, as it advances with the speed of a hurricane, causing a wind strong enough to upset houses and to carry trees and animals several hundred yards through the air. The ground avalanche as a rule descends at a comparatively slow speed, but carries with it earth, stones, trees, &c., which it has encountered on its path. The snow-dust avalanche is formed when the snow is newly fallen and the temperature is below freezing-point. On steep places favourable to the formation of avalanches, it may happen, when they are covered with fresh snow, that the wind causes a small snow-slip to start, or that some piece of overhanging snow falls and puts greater masses of snow in motion, at the same time raising a cloud of fine frozen snow-dust, which rapidly assumes increased proportions and descends with great velocity. A ground avalanche occurs when the snow has become somewhat dense and is caused to slip by the influence of thaw or other causes. It slides down, now rolling, now slipping, without raising any considerable amount of snow-dust, and sometimes advances very slowly. There is again a mixed type, partly snow-dust and partly ground avalanche.

Various means of defence are employed according to circumstances. In some cases, the line is tunnelled or is covered with a gallery. In other cases, works are carried out high up the mountain sides at the points where avalanches are likely to originate. These works consist either of stone walls or barriers made of wood, wood and iron, or (more frequently) of wooden posts and wattle-work. The walls are distributed in short lengths over the ground, having their sides at right-angles to the probable direction of the path of the avalanches. As these generally travel down the steep gorges on

the mountain sides, such places are barred by strong works of defence in order to break the force of an avalanche, or if possible, to stop it.

The side walls are nearly all made of dry stone. The top of the wall is seldom less than one yard above the ground-level at the up-hill side which is vertical, the down-hill face having a batter of one to one. It is inadvisable to cover the up-hill sides of these walls with earth slopes, except in places where falls of rock are to be feared, as such a slope enables avalanches to mount and pass over the wall.

The posts used for avalanche defence or to prevent snow-slips are, as a rule, 5 feet to 6 feet 6 inches long and about 6 inches in diameter. They are placed in rows and are driven into the ground for about half their length, the distance between the rows varying from one yard upwards, and the distance from post to post being about one yard. In some cases the posts are interwoven with branches, wattle-work being more serviceable than posts alone. In steep gorges, or in places where stone walls would be too expensive, "snow bridges," like hurdles placed horizontally in the angle of the gorge, are introduced. This construction is intended to stop or at least to obstruct avalanches or snow-slips. The opening between the timbers prevents the construction from being struck with the full force of the avalanche, which covers it with a layer of snow and, passing over it, travels with diminished momentum to the next defence. This kind of construction is, however, insufficient to arrest the greater avalanches. Some of the defence-walls on the St. Gothard Railway are formed of bars or rails of timber carried between uprights formed of pairs of old railway rails bolted and banded together.

Concerning the construction of galleries as defences against avalanches, the opinion has been advanced that care should be taken to avoid situating the entrances to the galleries in deep cuttings; as, if an avalanche should come outside the gallery, it would descend into the cutting, and, not having sufficient room for escape, would be forced to each side, and by thus filling the gallery would cause delay of traffic and possibly loss of life. If possible, the cuttings at the entrances to galleries should be levelled down on the side towards the valley. Care should be taken not to make the defence-works too low, because, if they are covered with snow, a heavy snow-fall may cause avalanches which will pass over the top of them.

The best protection against avalanches is afforded by woods.

Many places are too steep or stony, or at too high an elevation for the growth of trees. The upper limit of the forests in Switzerland is about 7,200 feet above sea-level. The *Pinus Cembra* and the straight-stemmed variety of *Pinus Montana* are useful trees for the purpose. Almost all risk of the occurrence of avalanches may be disregarded on a well-wooded hill-side.

Approaches of the St. Gothard Tunnel.

The general features of the St. Gothard railway are well known,[1] but some of its details may be appropriately mentioned in connection with mountain railways. The ruling gradient of the approaches to the great tunnel is 1 in 40, the maximum gradient on some shorter pieces of line being 1 in 37.

Nearly one-half the line is on curves, these often being of or near to the lowest limit of radius. At the ends of circular curves between 14 chains and 1¼ mile in radius, transition-curves are introduced. The equations for these transition-curves are—for curves of radius less than 600 metres—

$$y = \frac{x^3}{72{,}000}, \qquad l = \frac{12{,}000}{R};$$

for curves of radius between 600 and 2,000 metres—

$$y = \frac{x^3}{120 \cdot R}, \qquad l = 20,$$

when l = the length of the transition-curve in metres,
R = the radius of the circular curve „ „

and x and y are co-ordinates of the transition-curve. The transition-curve is placed half on the straight and half on the circular curve. The super-elevation h of the outer rail on curves is derived from the equation

$$h = \frac{1 \cdot 445\, v^2}{gR},$$

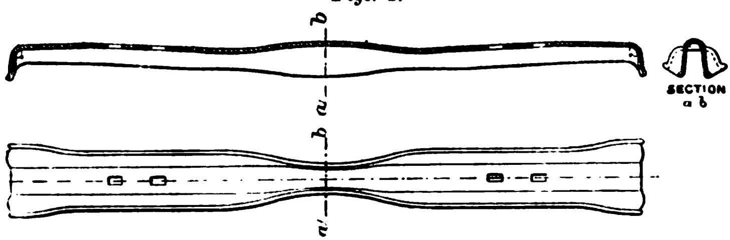
where v = maximum speed ($15 \cdot 63$ metres per second, *i.e.* 35 miles per hour); hence

$$h \text{ (millimetres)} = \frac{36{,}000}{R}.$$

[1] Minutes of Proceedings Inst. C.E., vol. xlii. p. 228; vol. liii. p. 164; vol. lvii. p. 239.

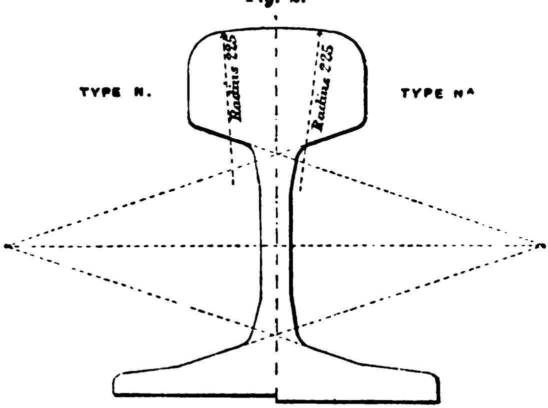
The super-elevation of the outer rail is commenced if possible the full length of the transition-curve before or after the commencement or end, respectively, of those curves; but if, as is often the case, the straight between the reverse curves is not long enough for this, the point of division between the two reversed elevations is chosen according to the ratio of the super-elevations. The widening of gauge on the curves begins with the transition-curve

Figs. 1.



Scale $\frac{1}{10}$.

Fig. 2.



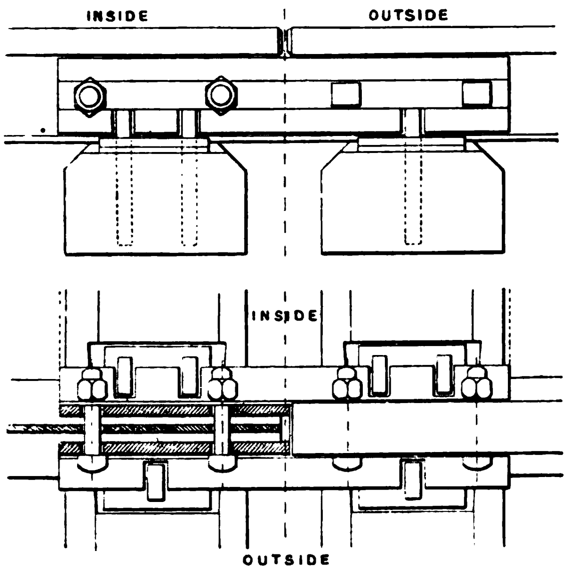
Scale $\frac{1}{4}$.

and increases gradually at the rate of $\frac{1}{2.000}$, reaching its maximum at the end of the transition-curve.

The weight of the rails has been considerably increased since the opening of the line. In the year 1881, rails weighing 72½ lbs. per yard were used; in 1888, the weight was increased to 74½ lbs. and 88¾ lbs., and in 1890 to 92¾ lbs. and 96¾ lbs. per yard. Before 1891, except for some unsuccessful trials with iron sleepers, which proved too light, oak sleepers only were used, 7 feet 10 inches by

9 inches by 6 inches. The steel sleepers used since 1890 have been satisfactory; they weigh 132 lbs. or 145½ lbs. each, the former weight being for sleepers with a varying and the latter for sleepers with a uniform thickness of top, the latter, *Figs. 1*, being the better type. The length of rail now in use is generally 39 feet 4 inches. *Fig. 2* shows sections of rail of types N and N^A, the latter type being used in the tunnels, where on account of the moisture the wear is more rapid than on the open parts of the line. *Figs. 3* show plan and elevation of a rail-joint on wooden

Figs. 3.



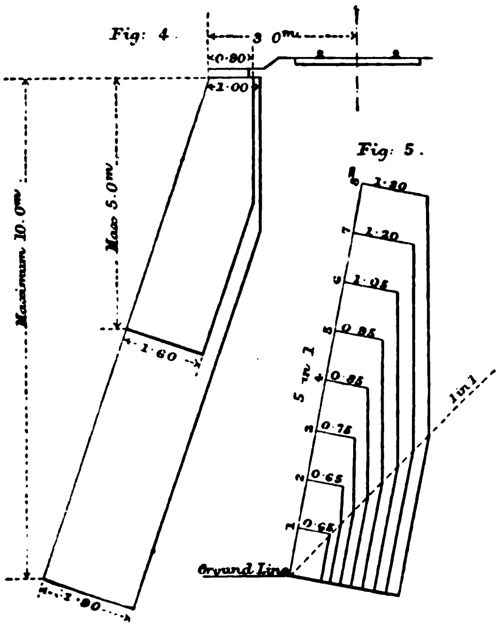
Scale, $\frac{1}{10}$.

sleepers. The rails rest on bed-plates and are joined by angular fish-plates. With the steel sleepers no bed-plates are used. Angular fish-plates are employed and the rails are fastened to the sleepers by hook bolts and clamps, the latter being of different dimensions to suit the widening of the gauge on curves. The material used for ballast is broken stone (granite or gneiss). The lower layer (5 inches to 11 inches) consists of pitching, the stones being principally of pyramidal shape and set as closely together as possible. The upper layer of the ballast-bed is of stone broken to pass through a 2-inch ring when used with steel sleepers

and through a 3-inch ring with wooden sleepers, the minimum dimension in both cases being 0·8 inch.

The approaches to the tunnel have now a double line of rails throughout, and the works for establishing the second line are somewhat recent and possess rather unusual interest. It was decided that this, the Erstfeld-Biasca section, should be constructed in such a way as to be capable of alteration without further great expense.

The great tunnel and some of the other tunnels were originally



Scale, $\frac{1}{150}$.

constructed for a double line, and much of the line, though at first made only single, was constructed in such a way so as to facilitate the subsequent widening. Only five years after the opening of the railway, the works for establishing a second line were commenced. The widening of cuttings in the softer material did not present any difficulty; whereas the deep rock-cuttings, which had to be widened by blasting-operations, were not easily dealt with. In some cases the cuttings to be widened were upwards of 100 feet deep. The cross-sections near the entrance of the

Leggistein tunnel and outside the Boscerina tunnel offered peculiar difficulties. The latter tunnel was originally only constructed for a single line, and the rock was so fissured that it was thought too risky to widen the tunnel and thus to increase the pressure on the outer rock wall, which was somewhat slender. Below, under overhanging rocks, lay the main road to Italy with the River Ticino on the left; and ahead of the tunnel was the Polmengo bridge of 206 feet span. The second line was run outside the spur pierced by the tunnel, and the somewhat weak rock-abutment on the outer side of the tunnel was strengthened with masonry. The embankments were widened either by side-tipping—some of the banks widened in that way being about 100 feet high—or by the introduction of dry stone retaining-walls, *Fig. 4.* The material for widening the banks was taken from the tunnels and cuttings; side-cutting being resorted to only in cases where the excavation from tunnels and cuttings was insufficient in quantity, or inconveniently situated for transport. The dry stone walls previously mentioned were as a rule founded in the old embankment; they were built to the dimensions indicated in *Fig. 4*, and as high as 33 feet. It was a cheap way of solving the problem of embankment-widening, and the walls have answered well. As a rule, they show little settlement (on the northern approach it is between 2 inches and 4 inches, though in some cases on the southern approach it is upwards of 16 inches); it was, however, very regular, and the only inconvenience occasioned was having to restore the walls to their proper height by adding an additional course of stone. Retaining-walls introduced in the widening of cuttings are nearly all built in mortar, and are, as a rule, of the dimensions shown in *Fig. 5.*

The widening of tunnels presented the most difficult work, as there was little room left between the existing line and the rock to be removed. Figs. 6, 7, and 8, Plate 1, show how the different types of the tunnel section (the choice of type depending upon the character of the rock) were left when first constructed. Where the rock was not considered firm enough, a lining of masonry was as a rule constructed with a space between it and the rock; this space was filled with dry rubble to let the water which percolates through the fissures of the rock drain down to the weep-holes at the rail-level, thus almost entirely preventing the destructive action of the water upon the masonry. Work in the tunnels was carried on principally at night, when the traffic

was least; although even then, the smoke remaining from the trains—particularly in the helicoidal tunnels—delayed the work considerably. The explosives used, both for tunnels and for open line, were blasting-powder, gelatine dynamite and "Favier" dynamite. The last-mentioned explosive is less dangerous to handle than dynamite whilst it seems to equal it in effect, but the exercise of great care is required in boring the holes.

Of the thirty tunnels on the approaches, only four, of an aggregate length of 312 yards, were originally constructed for a double track; one of 47 yards length was not widened, as the second line was taken outside the mountain; the remaining twenty-five tunnels (12,823 yards) were widened and were partly lined with masonry. The material excavated (all by blasting) amounted to 240,000 cubic yards, and the masonry lining amounted to 38,000 cubic yards. After completing the necessary excavation, the masonry for the widening of abutments and piers and the lengthening of arches was built in the usual way, with or without staging according to circumstances. Between the new and the old masonry all bond was avoided. The surface of the old masonry, where it had to be joined by new work, was dressed off—the surface of the original work being as a rule rock-faced granite—thus permitting the new masonry to settle without causing cracks through its hanging on to the rough sides of the old masonry. Several of the abutments and piers widened are very high; the Kerstelenbach pier, for instance, is 164 feet high, and shows no opening between the old and new masonry.

The girders were constructed to match those already existing. The larger spans, from 100 feet to 246 feet, are of the quadruple triangular system without verticals; spans of less than 100 feet are of the double triangular system with stiff verticals. There is, as a rule, plenty of room below rail-level, and most of the bridges carry the road on the top of the girders. On the bridges, the rails are spiked to cross-timbers which are bolted to the stringers, and on all the bridges the rails are checked. The total weight of girders constructed for the second line amounts to 5,229 tons, of which 3,132 tons are of wrought-iron and 2,097 tons are of steel. On the northern approach, three of the bridges (of spans respectively 131 feet, 144 feet and 184 feet) did not in their original positions suit the new centre-lines, and had to be shifted into new positions to give room for the new additional bridges. These works were done on Sundays, when there are as a rule no goods-trains, the line being blocked between ordinary passenger-

trains. The principal prices paid are given in Appendix II. These prices cover all cost of carriage, no allowance whatever being made in respect of quantity, kind of material, up-gradient or down-gradient.

The heavy goods-engines which run on the steep gradients are of special interest. The ordinary type weighs about 55 tons and has eight driving-wheels with a rigid wheel-base of 12 feet 9 inches. The tender is carried on four wheels. The total length of engine and tender over all is 48 feet 9 inches. The total weight in working order is 84 tons. The hauling-capacity is 170 tons net on the steepest gradients. For two years past a heavy goods-engine of the compound type ("Mallet" system) has been tried. It has a total weight of 84 tons in working order, and is carried on twelve driving-wheels which are arranged in two groups, the rigid wheel-base being 8 feet 10 inches. The foremost group of six wheels is on a bogey frame. This, a model goods-engine for mountain lines, having all its weight on the driving-wheels, travels easily on sharp curves and gives good results during the summer season; but it is less satisfactory during the winter season, when it seems impossible to prevent the steam from condensing owing to the low temperature then obtaining. The engine is rather complicated, but seems to be a decided step in the right direction, and the type will doubtless be improved. Its hauling-capacity on the steepest gradient is estimated at 200 tons net. The goods-trains are nearly always too heavy for one locomotive to draw, and an additional engine is generally put at the rear of the train. Running down-hill, the locomotives, one to three in number, are placed at the front of the train which runs down by gravity, the speed being regulated by brakes on the engines as well as on the wagons, on which a number of brakesmen are placed.

The Stanzerhorn Cable-Railway.

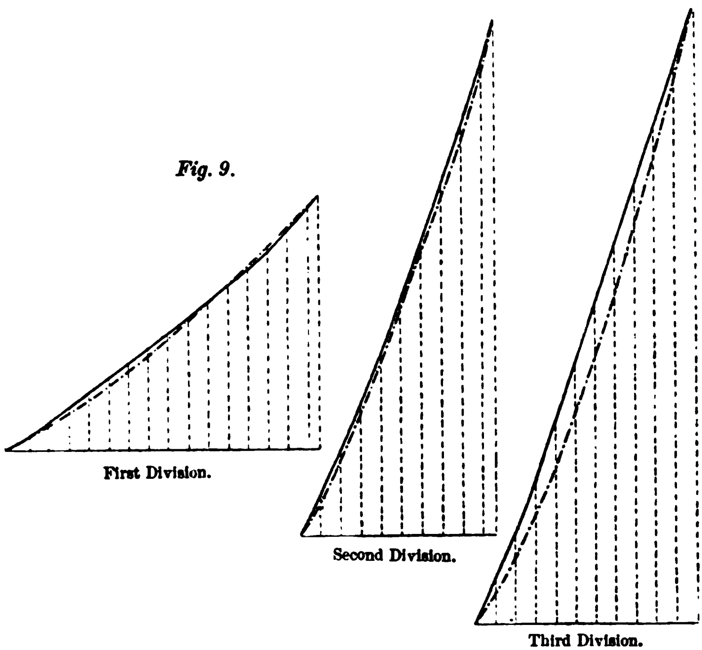
The Stanzerhorn line is perhaps the most noteworthy cable-railway in Switzerland. It affords a means of ascending the Stanzerhorn, which is a prominent peak lying on the southern side of lake Lucerne, attaining an elevation of 6,230 feet above sea-level.

The line commences at Stanz and terminates about 160 feet below the top of the mountain. It has three divisions, at the end

of each of which is a station. At each station there is an engine-house containing a dynamo-motor with a 60-HP. steam-engine as reserve for moving the cars, of which there are two on each division, one ascending as the other descends. The motive power is generated at Buochs, about 2½ miles distant, by a hydraulic motor developing 175 HP. and a dynamo, which supplies electric power to the Stanzerhorn and the Burgenstock cable-railways and to the Stanzstad-Stanz tramway. The stations have covered

Fig. 10. *Fig. 11.*

Fig. 9.



STANZERHORN RAILWAY.

platforms arranged with steps on an incline parallel to the inclination of the line.

The line has only two rails, except at the loops where the up- and the down-carriages pass one another. The first division, *Fig. 9*, commences with a gradient of 1 in 12½ and ends with 1 in 3·7; the second and third divisions, *Figs. 10* and *11*, both commence with 1 in 2½ and end with 1 in 1·6. The speed on the first division is about 6½ feet per second, and on the second and third

divisions about 4½ feet per second. The journey over each division lasts about thirteen minutes, and about forty-five minutes are occupied in travelling from the station at Stanz to the top station on the Stanzerhorn. The station at Stanz is 1,476 feet above sea-level, and the stations at the top of the first, second and third divisions respectively are 2,342 feet, 4,006 feet, and 6,070 feet above sea-level.

A novel feature of the line is this division into sections arranged to work independently of one another. The aim of this arrangement is to work a heavier traffic than would otherwise be possible, to obtain the easiest route, and to avoid the use of very long cables.

The division into separate lengths also renders possible a greater speed on the lower division than if it had to be worked together with the higher and steeper parts of the line, where only a low speed is permissible. Another novel feature is the omission of a rack for braking purposes. Braking by means of a cog-wheel working in a rack involves, especially on the heavier gradients, the danger of the wheel mounting the rack-teeth, which danger can only be counteracted or prevented by the introduction of an angular jaw to seize a projecting flange. The omission of the rack means of course a saving in the weight and the cost of construction of the permanent way.

The alignment is fairly straight, which is of advantage in working. The first division has two deflections, amounting together to 17° 46′, and curves of 492 feet and ¼ mile radius. The second division also has two deflections, amounting together to 33° 50′, and curves of 689 feet and ⅛ mile radius. The third division has one deflection of 56°, and a curve of ⅛ mile radius. The line is two-railed, and, in order to enable the up- and the down-carriages to pass one another, there is a siding midway on each division.

It was found possible in laying out this line along the mountain-side, to approximate the section fairly to the ideal or theoretical section. For this kind of line it is generally of special importance that the section chosen should be as favourable as possible for working. On cable-railways where the working-power is gained by adjusting the filling of a water-tank on the carriages at the top station, the section chosen must be kept rather close to the ideal section for working the line; as it is of importance to keep the quantity of water, by the weight of which the down-carriage has to haul up the up-carriage and overcome friction

and other factors of resistance, within as narrow limits as possible — a large water-tank being disadvantageous in regard to construction of the carriage as well as of the rest of the plant. In this case, where there is ample engine-power for working the line, the choice of section was not of supreme importance; but the nearer it approaches the ideal section shown dotted in *Figs. 9*, *10* and *11*, the better, and the line chosen enabled an excellent section to be used. Mr. Alph. Vautier,[1] of Lausanne, has developed formulas which give the ordinates for the best section, viz., that which is most economically worked at uniform speed.

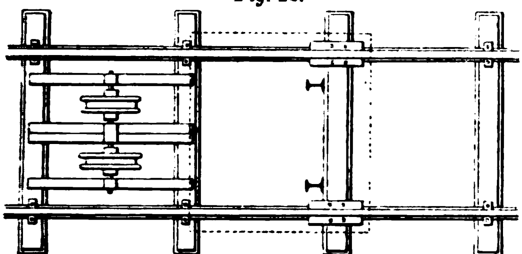
The gauge of the line is 1 metre. The rails, which are 4·9 inches high, weigh 40 lbs. per lineal yard. The joints are supported by a sleeper. The fish-plates are angular. The sleepers are of a trough shape and weigh 51 lbs. each. The distance between the sleepers is 1 metre and the length of rail is 10 metres. In order to prevent the track from sliding downwards, anchorages consisting of two iron I-bars placed vertically at the lower edge of a joint-sleeper and embedded in concrete blocks, are fixed at every fourth rail-joint. *Figs. 12*, *13* and *14*, show plan, cross-section and longitudinal section of the permanent way of the first division. On the second and third divisions the rails are of the same type as those on the first division, but the sleepers are formed of iron angle-bars 5 inches by $3\frac{1}{3}$ inches by 5 feet in length, laid 1 metre apart. The rail-joints and fastenings are the same as those of the first division. *Figs. 15* show the arrangement of joint and fastening. The angular fish-plate is bolted to the rail by four bolts with washers. The rails are bolted to the sleepers by four hook-bolts with washers and clamps. The weight of the permanent way on the second and third divisions is 135 lbs. per lineal yard.

The Cables.—The cable of the first division is 0·9 inch in diameter, and weighs $4\frac{3}{4}$ lbs. per lineal yard. Its maximum tensile strength is $24\frac{1}{2}$ tons. The cable of the second division is 1·3 inch in diameter, with a weight of $7\frac{1}{4}$ lbs. per yard. The maximum tensile strength is 51·2 tons. The cable of the third division is 1·34 inch in diameter, and weighs $8\frac{1}{2}$ lbs. per yard. The maximum tensile strength is 54·1 tons. On the first division the stress on the cable with the fully-loaded car is 3,873 lbs. when the car is at the lower end of the division, and 3,942 lbs.

[1] See "Nouvelles Annales de la Construction," vol. viii. pp. 137 and 138, Baudry & Cie., Paris, 1891.

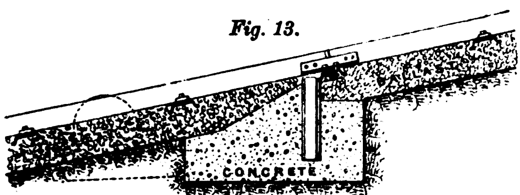
when the car is close to the engine-house at the upper end of the division. On the second division the stress on the cable is 9,822 lbs. when the car is at the lower end of the division, and 9,286 lbs. when the car is at the lower end of the steeper gradient

Fig. 12.



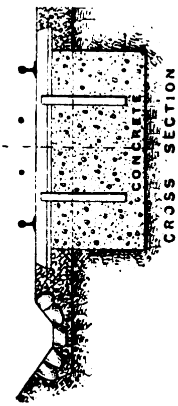
PLAN

Fig. 13.



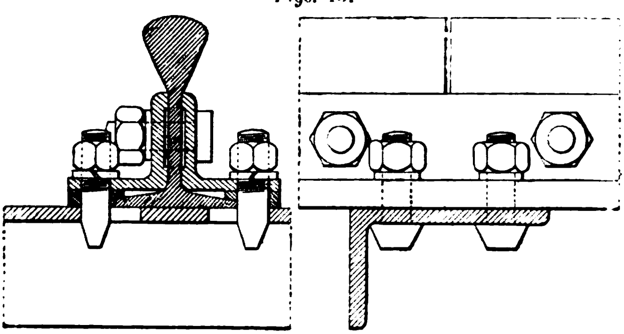
SECTION

Fig. 14.



Scale $\frac{1}{50}$.

Figs. 15.



Scale $\frac{1}{5}$.

(1 in 1·6). On the third division the stress on the cable is 11,570 lbs. when the car is at the lower end of the division, and 12,320 lbs. when the car is at the lower end of the 1 in 1·6 gradient

The upward and downward cables travel upon rollers with grooved edges $13\frac{1}{3}$ inches apart and are equidistant from the centre of the

track. The diameter of the rollers on the straight parts of the line is 11·8 inches, the intervals between the pairs of rollers being about 38 feet. On the curves, the rollers are 23·6 inches in diameter and are about 33 feet apart; they are placed at inclinations to suit the cables travelling round the curves. The rollers are made of cast-iron disks, with sectors of beech-wood between. The cable runs in a groove which is worked out on the edge of the beech-wood sectors, and is the only part of the roller touched by the cable. The disks are bolted together but are easily taken apart to allow of the renewal of the timber sectors, which takes place once every season on the lower third, twice on the middle third, and three times on the upper third of each division. The drums in the engine-house are also faced with beech-wood, and are grooved like the rollers. The casing of the drums lasts about three years. The way in which the cables are wound upon their drums is shown in Fig. 16, Plate 1. The cable from the carriage to be hauled up passes over the drum *a* to the lower edge of the drum *c*, which it leaves from its upper edge to pass to the upper edge of the drum *b*. The drum *b* is placed in an inclined position and is $13\frac{1}{3}$ inches out of plumb. The cable therefore leaves the lower edge of the drum *b* displaced $13\frac{1}{3}$ inches, and thus gets to the left part of *c* on the lower edge. After half a turn about the left part of the drum *c*, it passes from the upper edge of the drum to the down carriage. The diameter of the drums *a* and *b* is 9 feet 10 inches. The diameter of *c* is 13 feet $1\frac{1}{2}$ inch. The drum *c* is the main drum and is geared to the main engine-shaft. By this arrangement there is friction enough between the cable and the drums to prevent any slipping of the cable. The direction of rotation of the drums and the travel of the cable is indicated by the arrows.

The cars, Fig. 17, Plate 1, are arranged to accommodate thirty-two persons, but, as there is additional room on the platforms, they can carry forty passengers in all. The upper part is made of wood and is constructed as lightly as possible. It rests upon, and is fastened to, a strong iron frame, to which the axles and different braking-arrangements are attached. The car has four wheels keyed on to the axles. The wheels on one side of the car have double flanges, whereas the wheels on the other side are without flanges and are very broad. Arriving at the siding, the double-flanged wheel keeps the car to its through-rail, thus taking it automatically through the siding. The other broad wheels pass smoothly over the points. Each metal of the double-railed line

being a through-rail on the outer half of the sidings, the two cars on each division of the line have their double-flanged wheels on opposite sides.

The car has three brakes, I, II and III, Figs. 17 and 18, Plate 1. The brakes I and II act automatically if the cable breaks, and II can be applied by pressing on either of the levers *a* or *a'*. Brake III can be put on from either end of the car by means of a crank-handle and toothed-wheel gearing. The arrangement of the brakes is shown on Figs. 17 to 21, Plate 1. Fig. 21 shows the friction-coupling, of which one part *f* is keyed firmly to the carrying-axle; the other part is movable and able to slide along the axle for a certain distance. The movable part of *c* has four sections (Figs. 19 and 21), indicated by thick dotted lines (Fig. 19). These four sections can slide in and out in a radial direction as indicated by the arrows, and are supplied with tooth-grooved edges fitting into corresponding grooves on the inside of the edge of the cog-wheel *d*. The four sections of *c* are moved in and out by a collar-piece sliding along the axle; *p*, *q*, *r*, *s*, Fig. 19, indicate a section in its outer position. Fig. 21 shows the friction-coupling in action, the four movable sections of *c* being pushed on to *d*, thus causing it to rotate with the axle. The dotted lines indicate the position of the coupling when out of action. The cog-wheel *d*, geared to the wheel *e*, Fig. 19, is loose on the axle, the rotation of which it is prevented from following. The wheel *e* is keyed to a shaft passing through the upper ends of the brake-jaws, the latter being furnished with female and the shaft with male screws; thus the brake-jaws are by the rotation of the shaft either opened or closed according to the direction of rotation. Figs. 19 and 20 show a side view and section of the brake-jaws. The piece *b*, Figs. 17 and 18, turns about the shaft *o*. To one end of *b* the cable is attached, and the other end is saddled upon the shaft *h* so as to prevent its rotation as long as there is a certain tension at the cable end of *b*. As soon as that ceases, or falls below a certain amount, *h* is released. Upon *h* are keyed the weighted lever *f* and a drum with a slot *s*. Pivoted to a collar on the shaft *i* is a two-armed lever *l*, one end of which travels in the slot *s* while the other end is pivoted to the collar-piece of *c*. If the cable breaks, *b* is relieved from the stress of the cable and thus loses its hold upon *h* which is then turned by the weight of the lever *f*. By the turning of the drum keyed upon *h*, the other end of *l* forces the collar-piece of *c* against the wheel *d*, thus bringing the friction-coupling into

action; simultaneously, by the falling of *f*, the bar *m* is lifted and releases *e* and *d*, which are at once carried round by *c*, and, soon attaining the same velocity as the axle, screw the brake-jaws on to the rail and the car is brought to a standstill. When the lever *f* falls, it knocks out the piece *g* which supports the end of the lever f^1, which, losing its support, falls and puts on brake II in the same manner as that already described for brake I.

A wire is carried on the telephone-posts along the line about 6 feet 6 inches from the ground. This wire affords a means of communication between the guards travelling along the line and the engine-house, where the wire is connected with an electric-bell apparatus. By means of metal rods the guards can close the electric circuit, and thus give signals when necessary.

Trials of the brakes were made under the supervision of the Inspecting Engineers of the Swiss Government in November, 1892. Forty trials were made at various parts of the line on gradients ranging from 27 in 100 to 60 in 100, with the result that the car was, except in two cases, brought to a standstill after having travelled distances varying between 2 feet 3 inches and 12 feet from the moment the brake was applied. In the two cases mentioned, the car travelled 13 feet and 33 feet respectively before it stopped. These results were probably due to the coupling not acting quickly enough. When the jaws of the brake press against the rail they not only create friction, but also, on account of the tapered form of the rail, tend to force the wheel on to the rail.

In working the line, when the cars are ready to start, the guard of the car at the upper station of any one division communicates by electrical signal with the guard of that at the lower station, and, on receiving an acknowledgment, signals to the engine-driver at the upper station, who then starts the dynamo, takes off the brake and puts on the friction-coupling. This operation occupies about twenty seconds. To prevent the cars from running with full force against the terminal buffer at the engine-house, an automatic brake is applied, being brought into action by the car striking a lever as it approaches the terminus.

The line was constructed by Messrs. Bucher and Durrer at a cost of £58,000, and that firm has also taken a contract to work it for £1,500 per annum. For this sum they have to pay all working

expenses and maintenance, except the renewal of the cables and the insurance of the passengers.

The Paper is accompanied by two sheets of tracings, from which Plate 1 and the *Figs.* in the text have been prepared, and by Appendixes[1] containing particulars of the mountain railways of Switzerland, and of the cost of the widening of the St. Gothard line.

---

[1] For convenience of reference, information from other sources has been incorporated in Appendix I as furnished by the Author.—SEC. INST. C.E.

[APPENDIXES.

APPEN

APPENDIX I.—Table I.—Swiss

Name of Line.	Year of Opening.	Gauge.	Length of Line.	Length of Inclined Line.
		Feet. Ins.	Miles.	Miles.
St. Gothard Railway, northern and southern approaches of the great tunnel	1882	4 8½	65	about 54
Südost Railway sections:—Wädenschwyl, Rothenthurm, and Goldau . . .	1891	4 8½	19·8	..
Landquart - Davos narrow-gauge railway	1890–91	metre	31	28·4
Uetliberg Railway	1876	Feet. Ins. 4 8½	5·6	5·1
Jura Sud-Est, Vaud [1] . . .	1895	metre	11·9	..
Orbe-Chavornay [1]	1894	Feet. Ins. 4 8½	24	..
Swiss Lines partly Rack-and-Pinion and				
Brünig Railway	1888	metre	35·9	27·3
Appenzell Street Railway. .	1888	,,	8·6	8·1
Bern-Oberland Railway . .	1890	,,	14·5	12·3
Visp-Zermatt Railway . .	1891	,,	21·9	18·0
Rorschach-Heiden Railway .	1875	Feet. Ins. 4 8½	4·4	3·7
Swiss Lines wholly				
Arth-Rigi Railway . . .	1875	4 8½	7·1	6·8
Generoso Railway	1890	2 7½	5·5	5·2
Pilatus Railway	1889	2 7½	2·6	2·6
Vitznau-Rigi Railway. . .	1871	4 8½	4·2	4·2
Schynige-Platte Railway . .	1893	2 7½	4·5	4·5
Wengern Alp Railway. . .	1893	2 7½	11·1	11·1
Rothhorn Railway	1892	2 7½	4·7	4·7
Glion-Naye Railway . . .	1892	2 7½	4·7	4·7
Salève Railway, in Geneva [1] .	1892	metre	5·6	..

[1] From information furnished by

DIXES.

LINES ON THE PRINCIPLE OF ADHESION.

Elevation above Sea-Level at	Feet.	Total Rise and Fall.	Length of Line on Curves.	Maximum Gradient.	Length of Line on Rack-and-Pinion.	Remarks.
		Feet.	Miles.	In 100.	Miles.	
Erstfeld	1,558					
Göschenen	3,638	4,862	about 25·5	2·7		
Airolo	3,753					
Biasca	971					
Wädenschwyl	1,348					
Rothenthurm	3,038	3,045	..	5		
Goldau	1,683					
Landquart	1,726					
Wolfgang	5,358	4,127	12·0	4·5		
Davos	5,062					
Zürich	1,368	1,325	3·0	7	..	Cost £40,000.
Uetliberg	2,677					
Morges	1,260					
Suarmit	2,340	..	..	3·5	..	Cost £73,760.
Bière	2,278					
Orbe	1,533	..	..	2 5	..	Electric motors; cost, including generating stations, &c., £24,000.
Chavornay	1,478					

PARTLY ON THE PRINCIPLE OF ADHESION.

Elevation above Sea-Level at	Feet.	Total Rise and Fall.	Length of Line on Curves.	Maximum Gradient.	Length of Line on Rack-and-Pinion.	Remarks.
Luzern	1,437					
Brünig	3,094	3,832	13·3	12	5·6	Riggenbach rack.
Brienz	1,867					
St. Gallen	2,205	1,027	3·4	9·2	2·0	" "
Gais	3,015					
Interlaken	1,877					
Lauterbrunnen	2,621	2,111	6·3	12	2·7	" "
Zweilütschinen	2,149					
Grindelwald	3,369					
Visp	2,144	3,199	9·5	12·5	4·0	Abt rack.
Zermatt	5,277					
Rorschach	1,312	1,260	1·4	9	2·5	Riggenbach rack.
Heiden	2,572					

RACK-AND-PINION.

Elevation above Sea-Level at	Feet.	Total Rise and Fall.	Length of Line on Curves.	Maximum Gradient.	Length of Line on Rack-and-Pinion.	Remarks.
Arth	1,378	4,360	2·7	20	7·1	Riggenbach rack.
Rigi-Kulm	5,738					
Capolago	906	4,327	3·3	22	5·5	Abt rack.
Generoso-Kulm	5,233					
Alpnach-Stad	1,444	5,341	1,000·4	48	2·6	Locher rack.
Pilatus-Kulm	6,785					
Vitznau	1,440	4,298	1·7	25	4·2	Riggenbach rack.
Rigi-Kulm	5,738					
Schynige-Platte	6,463	4,593	..	25	4·4	" "
Scheidegg	6,772	4,150	..	25	11·1	" "
Rothhorn	7,388	5,515	..	25	4·7	Abt rack.
Naye	6,470	4,209	..	22	4·7	"
From	1,476	..	..	25	..	Abt rack (electric); cost £71,200.
to	3,839					

Mr. Louis Gonin, Lausanne.

TABLE II.—SWISS

Name of Line.	Year of Opening.	Gauge.	Length of Line.	Elevation above Sea-Level at	
			Yards.		Feet.
Beatenberg	1889	metre	1,750	Lake of Thun (Thunersee). Beatenberg	1,863 3,638
Biel-Maglingen	1887	"	1,777	Biel Maglingen	1,430 2,884
Bürgenstock	1888	"	904	Lake of four Cantons (Kehrsiten) Bürgenstock	1,437 2,880
Ecluse-Plan (Neuchâtel)	1890	"	402	Ecluse Plan	1,450 1,808
Giessbach	1879	"	350	Lake of Brienz Hotel Giessbach	1,880 2,175
Gütsch (Lucern)	1884	"	155	Untergrund Gütsch	1,454 1,700
Lausanne-Ouchy	1877	Ft. Ins. 4 8½	1,620	Lausanne Ouchy	1,575 1,240
Lauterbrunnen-Grütschalp	1891	metre	1,320	Lauterbrunnen Grütschalp	2,677 4,872
Lugano	1886	"	260	Lugano Railway station	919 1,106
Marzili (Bern)	1885	Ft. Ins. 2 7½	110	Marzili Bern	1,667 1,772
Salvatore	1890	metre	1,648	Paradiso San Salvatore	922 2,894
Territet-Glion	1883	"	605	Territet Glion	1,280 2,261
Zürichberg	1889	"	178	Limmat quai Polytechnicum	1,355 1,480
Ragaz-Wartenstein	1892	"	833	Ragaz-Wartenstein	676
Stanzerhorn	1893	"	3,959	Stanz Stanzerhorn	1,483 6,063
Cossouay-Gare, Vaud[1]	1894	"	1,334	Cossouay Gare Jura-Simplon	1,859 1,417
Rives-Thonon[1]	1888	"	252	to	1,390 1,237

[1] From information furnished by

CABLE-RAILWAYS.

Maximum Gradient.	Cost of Construction of Line.	Cost of Cable-Motor and Rolling-Stock.	Total Cost.	Remarks.
Per 1,000.	£.	£.	£.	
400	19,400	7,500	27,100	Water-tank, Riggenbach rack.
320	15,300	2,400	18,000	,, ,, ,, ,,
575	8,600	5,900	14,600	Dynamo by hydraulic motor, Abt rack.
370	6,700	1,000	7,700	Water-tank, Riggenbach rack.
320	5,000	840	6,000	,, ,, Riggenbach rack.
530	2,800	600	3,400	,, ,, ,, ,,
116	121,300	1,200	134,900	Hydraulic motor (turbine).
600	28,400	1,200	29,800	Water-tank, Riggenbach rack.
238	6,400	900	7,400	,, ,, Abt rack.
302	2,000	800	2,800	,, ,, Riggenbach rack.
600	22,200	1,200	23,600	Dynamo by hydraulic motor, Abt rack.
570	17,400	1,200	18,900	Water-tank, Riggenbach rack.
260	9,400	760	10,400	,, ,, ,, ,,
304	..	..	..	,, ,, ,, ,,
620	..	..	56,000	Dynamo by hydraulic motor.
130	..	..	14,000	Water-tank, Abt rack.
220	..	..	10,400	,, ,, ,, ,,

Mr. Louis Gonin, Lausanne.

APPENDIX II.

Widening the St. Gothard Railway.

Summary of prices paid.

	Price per cubic yard. *s.*	*d.*		*s.*	*d.*
Widening cuttings, according to the class of material excavated	1	6	to	4	10
Tunnels—					
Top excavation, for the longer tunnels	6	10	„	8	6
„ „ shorter „	4	3	„	7	2
Side excavation	12	2	„	24	4
Masonry in side walls	9	8	„	15	0
Masonry—					
Retaining-walls and abutments and wing-walls of culverts built in mortar	7	11	„	12	2
Arches (exclusive of the tunnel face)	20	10	„	27	4
„ (tunnel face)	36	6	„	48	8
Greater bridge piers and abutments	12	2	„	17	7
Masonry of large blocks, roughly dressed on all sides	54	9	„	73	0
Dry stone masonry built in courses	2	5	„	6	1
Dry stone masonry roughly built	1	2½	„	2	8¾
Ballasting—					
Pitching	1	6	„	1	10
Top ballast of gauge 0·8 inch to 2 inches	3	3	„	3	7½
	Price per square yard.				
Sixteen-inch thick stone coating of slopes of embankments, the inclination of slopes ranging from 1 in 1 to 1 in 1½	0	6½	to	1	4
Paving of ditches, dry or in mortar, according to the conditions	1	7		3	4

Laying permanent way, 11½*d.* per yard.
Girders, including erection, £17 1*s.* 8*d.* to £19 3*s.* 4*d.* per ton.

The daily wages paid were:—	*s.*	*d.*		*s.*	*d.*
Ordinary labourers	2	6	to	3	4
Miners	3	4	„	3	9
Masons	4	2	„	5	0
Stonecutters	3	9	„	4	7

The transport of material from the cuttings to the embankments or spoil-banks was paid for according to the rates given in the following Table—

Distance.	5 yards.	100 yards.	400 yards.	1,000 yards.	1 mile.	1¼ mile.
Price per cubic yard.	1*d.*	2½*d.*	4½*d.*	6¾*d.*	9*d.*	11*d.*

(*Paper No. 2783.*)

"The Monistrol-Montserrat Rack-Railway."[1]

By Alfred Collett, M. Inst. C.E.

From the time when Blenkinsop made the first rack-engine in 1811, discarded because Stephenson found that sufficient adhesion could be obtained on smooth rails, great changes have taken place.

The first rack-railway for heavy traffic was constructed by Cathcart on a short piece of the railway between Madison and Indianapolis[2] in 1847. In 1869 Mr. Marsh opened the Railway on Mount Washington with his ladder-rack,[3] and subsequently Mr. Riggenbach and Mr. Abt developed their systems of rack.[4]

Riggenbach ladder-rack.—This system has met with considerable success, but, in the Author's opinion, it is not as durable or as effective as the Abt rack, and the pitch of the teeth does not allow the constant action of the pinions described later. The Riggenbach rack is used on the Petropolis Railway, Brazil, on many Railways in Switzerland,[5] as well as in Austria and Germany.

Abt rack.—There are three systems of rack-engine in general use—(1) Adhesion and rack combined, as on the Hartz Railway; (2) Pinion coupled to driving-wheels, as on the Oertelsbruch Quarry sidings; and (3) Pure Rack, as on the Montserrat, Puerto Cabello-Valencia (Venezuela), and Revard Railways. In the Abt system of rack and adhesion combined, the two outside cylinders which work the adhesion driving-wheels operate throughout the whole line; and, just before the engine enters the steep gradients fitted with the rack, the two inside cylinders which work the coupled pinions running in the racks, are started. To

[1] The discussion upon this and the preceding and succeeding Papers was taken together.

[2] Transactions American Society of Civil Engineers, vol. vii. 1878, p. 68.

[3] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 260.

[4] The Telfener rack as applied on the S. Ellero-Saltino Railway is described in Minutes of Proceedings Inst. C.E., vol. cxvii. pp. 278 *et seq.*

[5] See Appendix I, Table I, "Mountain Railways, Switzerland," *ante* pp. 20 and 21.

enable the pinions of the engine to pass easily on to the rack, Mr. Abt has designed a piece of rack on springs, which is fixed at the commencement and end of the rack portions. Each plate of the rack is 6 feet long, 4·33 inches high, and varies in width according to the work to be done; when the rack consists of two plates, these are laid so that a tooth of one is opposite a space of the other, and thus the teeth on the two plates are half the pitch, which is 4¾ inches, apart. When three plates are laid, they are placed so that the teeth break joint at one-third of the pitch apart; the engine, therefore, on the three-plate rack exerts, with its six pinion-wheels, a powerful and constant action on the rack. The wear of the rack is found to be almost inappreciable, and the teeth of the pinion-wheels will last some ten years without renewal. The advantages of the rack are, that it prevents slip, is little affected by weather, can be used on any curve suitable to the locomotive and train, and enables the engine to exert twice the tractive power it would develop by adhesion alone. On the other hand, the speed is at present somewhat low, being, say, 6·2 miles per hour on 1 in 16 gradients, 4·35 miles per hour on 1 in 7 gradients, and 3·1 miles per hour on 1 in 4 gradients.

Fell system.—This system has done good work. On ordinary inclines it is very safe, with its powerful brake on the centre rail, which is somewhat cheaper than the rack-rail; but, as will be seen by reference to the Table in the Appendix, this class of engine has not the hauling-power of the Abt combined engine, and precautions have to be taken to prevent slipping when it is employed.

The Monistrol-Montserrat Railway.

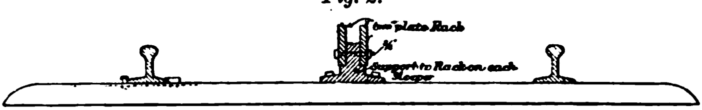
This Railway was built to convey visitors and pilgrims to the Montserrat Monastery, which is considered to be one of the most interesting places in Spain. The monastery is situated halfway up the mountain of Montserrat in the province of Catalonia, about 18 miles distant from Barcelona. Access to it was until recently obtained by means of coaches which took three-and-a-half hours to perform the journey between the railway-station of Monistrol, on the Northern of Spain Railway, and the monastery. Lately, however, a rack-railway has been constructed up the face of the mountain from Monistrol to Montserrat; and, as the cheapness of its construction, the steepness of its gradients and the sharpness of its curves afford points of interest, the Author ventures to bring before the Institution the results of his inspection of it at different times during its construction and since. The

summit of Montserrat is 4,068 feet above sea-level; the monastery is situated at 2,395 feet, the terminus of the railway at 2,360 feet, and the commencement of the line at 632 feet above sea-level. The mountain of Montserrat belongs to the Eocene formation, consisting of composite materials, the detritus of older rocks. These primary materials form a strong conglomerate which, in process of time, by chemical action and the erosive action of water, has assumed the most fantastic shapes; and the roughness and inequality of the various peaks have given to the whole mass the name of Montserrat, or the serrated Mountain. Travellers from Lerida, Barcelona, Madrid, &c., now take the broad-gauge railway to Monistrol Station, where they change for the rack-railway to the Monastery Station.

Surveys.—Various surveys of the line have been made at different times, but finally Mr. Abt selected the route now adopted and set out the line with considerable skill. The sharpest curves are of 213 feet radius, some of which are reverse curves.

Works.—The following works occur on the line:—a fine stone bridge, with an 82-foot arch over a watercourse on a gradient

Fig. 2.



Scale, $\frac{1}{10}$ full size.

ABT RACK, MONTSERRAT RAILWAY.

of 1 in 17; a well-built iron bridge, with stone piers, consisting of three spans of 115 feet each, over the River Llobregat; and a tunnel in rock, 656 feet long, on a gradient of 1 in 6·6 and on a 213-foot curve. The gradients are given in Fig. 1, Plate 2, which shows a section of the entire line, the steepest gradient being 15 in 100.

Permanent Way.—The rails, *Fig. 2*, are of steel and weigh 40 lbs. to the yard, the lengths varying between 21 and 31 feet; the gauge is 1 metre; the transverse sleepers are of steel, 6 feet long, and weigh 59 lbs. each; they are placed 3 feet apart at the intermediate sleepers and 1 foot 6 inches apart at the rail-joints. The rack is double, made of two parallel plates bolted together, and is carried by supports fixed in the centre of each steel sleeper; each rack-plate is 6 feet long, 4½ inches in height and $\frac{7}{8}$ inch in thickness, and is cut with teeth to take the rack-pinions of the loco-

motives and carriages; the plates are laid to break joint. The permanent way is anchored by strong iron rails planted vertically in the ground at intervals, and one side of the sleepers abuts against these rails; this method seems to be quite effective in preventing the road from sliding. The fish-plates are 1 foot 10 inches in length and rest on the joint-sleepers; they are notched to receive the heads of the rail- and sleeper-fastenings. The banks are supported on the valley side by fine stone walls of dry masonry, of which material plenty was obtained from the rock-cuttings. The ballast, which consists of broken stone, is enclosed by small rock walls of dry masonry 18 inches high, running parallel with the rails throughout the mountainous portion of the line; the outside measurement of the ballast and walls is 10 feet.

Stations.—There are three stations, one at the commencement of the line near the Monistrol Station of the Northern of Spain Railway, a second at the Town of Monistrol (3·75 kilometres), where workshops have been erected, and the third at the end of the line (7·75 kilometres) at the Monastery of Montserrat.

Locomotives.—The intention at first was to work the line on the Fell system, but a rack was afterwards chosen as more suitable to the steep gradients and to the traffic, which consists chiefly of passengers. The engines, on the Abt system, have three axles; the two pairs of leading wheels are 2 feet 2 inches in diameter, and their axles are fitted with toothed pinion-wheels 17 inches in diameter, which run in the double rack; the carrying-wheels are loose on these axles but are fixed on the trailing-axle, the engine being propelled not by adhesion but by the double-toothed pinion-wheels working in the rack. The cylinders are two in number, 12 inches in diameter, with a stroke of 14 inches; the rigid wheel-base is 4 feet 8 inches and the total wheel-base is 9 feet 11 inches. The boiler has 355 square feet of heating-surface, was tested to 294 lbs. per square inch, and is worked at 206 lbs. pressure per square inch. The weight of the engines is 17 tons when loaded and 13 tons when empty. The consumption of coal is considerable, amounting to 40·8 lbs. per mile run. No doubt this will be reduced. It is intended to use heavier engines of a more powerful description, the present locomotives, the tractive force of each one of which is 13,100 lbs., being limited to drawing two carriages weighing 11 tons each on a 1 in 6·6 gradient at a speed of 7 kilometres (4·3 miles) per hour, and to a speed of 18 kilometres (11·2 miles) an hour on the level, and to 7 kilometres (4·3 miles) per hour on curves of 213 feet radius.

Carriages.—The carriages are 33 feet in length and are carried

on bogie-frames, those which carry first- and second-class passengers combined, seating 50 people and having a compartment for luggage, those which are fitted for second class only seating 60 persons. All have combined buffer and centre couplings. One of the axles of each of the carriages is fitted with a toothed pinion-wheel which runs in the rack, and is retarded by a band connected with the hand-brake which the guard works from the front platform of each carriage.

Brake-Power.—The trains are well provided with brake-power. On the locomotives there are two powerful ribbon-brakes working on each of the drums of the toothed pinion-wheels. They are independent of each other, one being worked by the driver and the other by the fireman. The carriages, as already mentioned, are also fitted with a hand-brake worked by the guard of the train. Besides these hand-brakes there is the air-brake (Abt system) which is chiefly used in descending the inclines and is worked in the following manner. Whether ascending or descending, the engine is placed below the train and controls the speed. Before the brake is put on, the lever is placed in forward gear, towards the ascent; communication is then opened to two tubes in front of the engine by which air is drawn in; this air is carried to the cylinders where a small jet of cold water plays upon it, and thus acts as a buffer against the pistons. This brake, after some practice in its use by the engine-drivers, gives good results.

Haulage.—Reference to the Table in the Appendix will show that the engines on this railway haul a load of 1·41 ton per ton of engine-weight, and that this compares fairly with the working of mountain railways in other parts of the world. The Author has compiled the following figures to show the gradients and the loads hauled in a few instances in actual practice with the adhesion and the rack systems:—

Gradient.	Load Hauled per Ton of Service-Engine Weight.	System.
	Tons.	
1 in 28·00	2·5	Adhesion
1 „ 27·00	2·02–2·66	„
1 „ 25·00	1·39–1·65	„
1 „ 16·67	2·14–2·45	Rack
1 „ 12·50	1·66–2·35	„
1 „ 8·00	1·55	„
1 „ 6·60	1·41	„
1 „ 4·00	0·78	„
1 „ 3·90	0·57	„

The Montserrat railway has not been working for a sufficiently

long period to render the results of the cost of haulage of much value, but the Author has made the following comparison, according to a method employed by Mr. R. Wilson,[1] on the basis of the load multiplied by the total height through which it is raised, or, in other words, on the basis of the work performed in overcoming friction and gravity. On this basis the following is a summary of the cost of haulage on an example of each of the rack, adhesion, wire-rope and centre-rail systems:—

—	Per Train-Mile.		Per 1,000 Foot-Tons.
	s.	*d.*	*d.*
The Hartz Railway (Abt) . .	1	0	2·3
Semmering Railway (adhesion)	1	5	3·0
São Paulo (wire-rope) . . .	3	0	3·4
Rimutaka incline (centre-rail)	3	8	3·5

Of course, the price of fuel, &c., varies very much, and this must be taken into consideration in employing the results arrived at.

General.—As a rule twelve trains are run daily in the season, but whenever the traffic demands it, special trains of two carriages each are provided. The railway was constructed in twelve months, and was opened in 1892. The speed attained is low and the working of the engines not all that could be desired, and at times there is considerable oscillation; but in the Author's opinion these defects can be remedied. The arrangements for the safety of the passengers are satisfactory and the engines and rolling-stock pass the sharp curves without grinding.

The Author is indebted to the Director of the Railway, Mr. Macaya, and to the Manager, Mr. Rosnay, for the facilities given him on the occasions of his visits to the line.

The Paper is accompanied by three tracings, from which Plate 2 and the *Fig.* in the text have been prepared, and by an Appendix containing particulars of mountain railways in various parts of the world.

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 134.

[APPENDIX.

APPENDIX.[1]

The Author, having had occasion to inspect various mountain railways, has compiled a Table showing the different systems of hauling-power used, the chief dimensions of the engines, the gauge, sharpest curve, maximum gradient, the ordinary and exceptional loads hauled, and the ratio they bear to the weight of the engine. In Plate 2 many different types of engine used on mountain railways are shown; these have all been reduced to the same scale in order to permit a general comparison to be made of their appearance and motions. In compiling the Table, the Author has selected for comparison examples of ordinary and special adhesion Fairlie engines, Fell, Riggenbach and Abt rack systems and wire-rope traction. In some cases other types of engines not specified in the Table, with different weight and hauling power, are used on the same line. The sharpest curves are given in metres and in feet, but other dimensions are reduced to English measures as far as possible. The steepest portions of the gradients are given as being to a great extent the crucial test of the load hauled. The statement of average load hauled has been prepared chiefly from information kindly supplied by the makers of the engines and by some of the engineers.

In the following notes, the numbers refer to those at the heads of the columns in the Table, and the capital letters to the types of engine illustrated in Plate 2:—

1. *Ceylon Government Railways.*—Kadugannawa Incline.[2] (Type A.)—The bank-engine is placed in front when the train exceeds sixteen vehicles and the ordinary train-engine is placed in the rear. These bank-engines when worked at full power consume one cwt. of coal and 117 gallons of water per mile; their length of stroke and great heating-surface are noticeable features.

2. *New South Wales Government Railways.*—For further information see p. 70.

3. *Indian State Railways.* (Type D.)—These are twin engines of great power and weight, built by Messrs. Neilson; they consist of two independent engines and one large tender; each engine weighs 43 tons 11 cwt. in working order. The six-wheeled tender carries 3,000 gallons of water, has 384 cubic feet of coke space, and weighs 40 tons 18 cwt. when loaded.

---

[1] For convenience of reference, information derived from other sources has been incorporated in the table and notes of this Appendix as furnished by the Author. The additions so made are columns Nos. 2, 4, 10, 11, 14, 15, 21, 27, 32, 33 and the corresponding notes. No. 2 has been supplied by Mr. R. H. Burnett; Nos. 4, 10 and 11 have been supplied by Mr. A. Mallet; also No. 10, independently by Mr. Schucan, of Davos-Platz; No. 14 by Mr. Foster Crowell, of New York; No. 15 by Mr. M. J. Becker, of Pittsburgh, U.S.A.; Nos. 21, 27 and 33 by Mr. A. Theurer, of Esslingen; No. 32 by Mr. Fellmann, of Lucerne. The particulars of cost have all been supplied by Mr. W. J. Weightman.—SEC. INST. C.E.

[2] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 67.

4. *Cape Government Railways.* (Type B.)—The engine was built by Messrs. Neilson to burn colonial coal; its tender is carried on bogies.

5. *St. Gothard Railway.*—See Mr. Berg's Paper, p. 5, and Appendix thereto, p. 20.

6. *Darjeeling Railway, Himalayas, India.* (Type C.)—The engine was built by Messrs. Sharp, Stewart & Co., and is interesting on account of the small gauge and exceedingly sharp curves upon which it works. Some of the engines have a wheel-base of 4 feet 3 inches: but the 5-feet 6-inch wheel-base shown in the type has given satisfactory results. It is often found that light engines on a small gauge have good hauling-power, and the load hauled in this instance is exceedingly satisfactory, especially when the great length of up-hill gradients is taken into account. Besides the saddle-tank there is a water-tank of 600 gallons capacity between the frames.

7. *La Guaira-Caracas Railway, Venezuela.* (Type F.)—The engine was built by Messrs. Beyer, Peacock & Co. The three pairs of wheels are coupled together, and the trailing bogie has a radial arm to assist in passing the extremely sharp curves of 140 feet radius. The hauling-power has proved very satisfactory, as these powerful adhesion engines, for the first six months of their working hauled 68·6 tons, but now haul 51·5 tons, per journey; this change having been made in order to increase the speed so as to cover the distance of 23 miles on a continuous incline of 1 in 27 in one hour and fifty minutes, including stoppages.

8. *Mexican Railway.* (Type G.)—The powerful Fairlie tank-engine used here was built by Messrs. Neilson. The heating-surface is very great, owing to the length of the boiler. The tank-capacity of this engine is 2,850 gallons, and the fuel-space is 300 cubic feet.

9. *Callao-Oroya Railway, Peru.*—This railway, from its age and the considerable engineering difficulties encountered in its construction and working, is of great interest. It rises to a height of 15,679 feet above the sea, in a distance of 124 miles, a great portion of the line, some 100 miles, consisting of 1 in 25 gradients, while there are several reversing-stations. The trailing wheels and bogies of the engine alone have flanges.

10. *Landquart-Davos Railway.*—See remarks by Mr. Schucan on p. 139, and Appendix to Correspondence, p. 148.

11. *Yverdon.—St. Croix Railway.* See Remarks by Mr. Mallet, p. 133.

12. *Hartz Railway* (Fig. 3, Plate 2). (Type H.)—This railway commenced to work in 1885. The rack is formed of three parallel plates all laid to break joint. The speed with a heavy load on the rack portion of the line is 6¼ miles per hour. This line has carried in one year 80,000 passengers and 170,000 tons of goods. The engine develops a tractive force of 25,574 lbs.

13. *Mostar-Serajevo Railway, Bosnia* (Fig. 4). (Type I.)—The engine commenced working in 1890; it is arranged for adhesion and rack, and can develop, at the working pressure of 172 lbs. per square inch, a tractive force of 16,755 lbs.

14. *Tiadaghton-Fahnastalk Railway.*—See remarks by Mr. Foster Crowell, p. 127.

15. *Madison and Indianapolis Railway.*—See remarks by Mr. Becker, p. 124.

16. *Indian State Railways.* (Type E.)—This powerful tank-engine, built by the same makers as No. 3, is notable on account of its great heating-surface. The tank-capacity is 1,550 gallons and the fuel-space is 90 cubic feet. The railway for which it was built is described in the Proceedings Inst. C.E., vol. cxii., p. 311.

17. *New Zealand Railways.*—Rimutaka Incline.[1] (Type J.)—The radial Fell

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 50, and vol. xcvi. p. 137.

tank-engine was built by Messrs. Neilson. It has four cylinders, two working on the driving-wheels in the ordinary way and two on the horizontal wheels which exert side pressure on the centre rail of the Fell system. The tanks of this engine hold 660 gallons, and the capacity of the coal-bunker is 36 cubic feet. The engines are only used on the incline, and Mr. Fell has stated that the rails of the main line are not heavy enough to allow their employment thereon.

18. *Eisenerz-Vordernberg Railway, Styria* (Fig. 5).—The engine works by adhesion and rack as on the Hartz railway, and can exert a tractive-force of 28,000 lbs. The rack consists of two parallel plates.

19. *Puerto Cabello-Valencia Railway, Venezuela.*—Trincheras incline. (Type K.)—This railway was opened for traffic in 1888 and has been described in the Proceedings of the Institution;[1] it is 34 miles in length and with the exception of the Trincheras incline is worked by ordinary adhesion engines. The engine working the incline was built by Messrs. Beyer, Peacock & Co., under the Abt, Lange and Livesey patents; it is a pure rack-engine of improved type and of great hauling-power. The carrying-wheels of the engine are not coupled and the trailing bogie has a radial arm pivoted under the fire-box. The two rack-wheels have independent axles, as will be seen on reference to the type sketch, and are driven by four independent cylinders.

20. *Oertelsbruch Railway, Saxe Meiningen* (Fig. 7).—This railway, which was opened in 1886, joins Oertelsbruch with the railway station of Lehesten, and has a total length of 2,950 lineal yards, of which 1,640 consist of ordinary permanent way with gradients ranging up to 1 in 28·5, and the remaining 1,310 are fitted with a rack which is formed of two parallel plates. The engine can develop a tractive-force of 13,663 lbs.

21. *Padang Railway, Sumatra.*—See Zeitschrift des Vereines Deutscher Ingenieure, 1891, p. 634, and abstract of same article in Minutes of Proceedings Inst. C.E., vol. cv. p. 370; also Revue Générale des chemins de fer, July, 1891, p. 14.

22. *Cantagallo Railway, Brazil.*—This railway now belongs to the Leopoldina Company. Besides the 6 miles of incline of 1 in 12, there are 5 miles with gradients of 1 in 33 and 1 in 14. The engine was constructed in the shops of the Baldwin Locomotive Works, Philadelphia. The railway was worked for a long time with Fell engines (part of the old Mont Cenis stock), but the present adhesion engines are reported to give a better return and to be cheaper. They are constructed with tenders, and the centre pair of the three-coupled sets of wheels have no flanges. These engines haul 40 tons of load at a speed of 8·7 miles per hour up an incline of 1 in 12. In the descent of the incline the centre rail of the Fell system is still used for the brake.

23. *São Paulo Railway, Santos incline, Brazil.*[2]—The Author considers this cable incline a most practical and successful one, the tonnage annually carried over it being about 700,000 tons. In a length of 5 miles, the inclines rise 2,650 feet and are divided into four sections, the following being the chief precautions taken in working:—The cables, which are of steel and consist of forty-two wires forming a total diameter of 1⅝ inch, work with one-tenth of the load to which they have been tested, and as soon as they show signs of deterioration are withdrawn from service. There is an electric connection which allows the guard of the train in the brake-van to communicate with the driver of the stationary engine. The brake-power is found to be satisfactory.

---

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 120.

[2] *Ibid*, vol. xxx. p. 29, and vol. lxiii. p. 128.

24. *Visp-Zermatt Railway, Switzerland* (Fig. 10).—This is a passenger railway, used chiefly by tourists. The engines are built on the Abt system for adhesion and rack, the steepest gradient on the adhesion portion of the line being 1 in 40. The rack consists of two parallel plates. The engine can develop a tractive force of 22,660 lbs.

25. *Diakophto Railway, Greece* (Fig. 8).—The length of this narrow-gauge line is 22 kilometres (13·7 miles) of which 3·5 kilometres (2·2 miles) are fitted with rack; it commenced to work in 1891. In the adhesion portion of the line there are curves of 33 yards radius. The engine, which is constructed for adhesion and rack combined, can take a load of 16 tons at a speed of 9·3 miles per hour up gradients of 1 in 28 on the adhesion portion of the line, and at a speed of 3·7 miles per hour up the rack incline of 1 in 6·9. The tractive force which it can develop is 11,023 lbs.

26. *Monistrol-Montserrat Railway, Spain.* (Type L.) (Described in the Paper.)

27. *Rüdesheim-Niederwald Railway.*—A tourist railway from Rüdesheim on the Rhine to the national monument on the Niederwald. A rack is laid for the whole distance. Tractive power of locomotive, 6·5 tons. The Drachenfels Railway on the Rhine is a similar line laid with the Riggenbach rack.

28. *Revard Railway, France* (Fig. 9).—This railway runs from Aix-les-Bains to the Revard heights and rises 6,562 feet in 5·6 miles. It is fitted throughout its length with a rack consisting of two parallel plates. The steel rails weigh 40 lbs. to the yard, and the single carriage pushed accommodates sixty passengers.

29. *Generoso Railway, Switzerland* (Fig. 11).—This is also a passenger line, with a rack throughout consisting of two parallel plates. The single carriage pushed accommodates fifty-six passengers. For description, see Schweizerische Bauzeitung, Bd. xviii. p. 77, September, 1891.

30. *Pike's Peak Railway, United States* (Fig. 13).—The engine travels on the steepest gradient of 1 in 4 at a speed of 3·1 miles per hour, and pushes two carriages carrying 100 persons. For description, see *Engineering*, 1891, Part II. p. 262, and *Railroad Gazette*, 1891, p. 90, February 6.

31. *Rothhorn Railway, Switzerland* (Fig. 12).—A passenger line. For description, see *Engineering*, 1892, Part II. p. 593.

32. *Vitznau-Rigi Railway, Switzerland.*—See remarks by Mr. Fellmann, p. 128.

33. *Salzburg-Gaisberg Railway, Tyrol.*—A tourist line with numerous gradients of 1 in 4. It extends from the railway station of Parsch, near Salzburg, to the top of the Gaisberg. A train accommodates sixty persons. Iron sleepers; rack laid throughout. Tractive force of locomotives, 9·5 and 7 tons.

34. *Schafberg Railway, Austria.*—Also a passenger line.

NOTE.—For information with regard to numerous other mountain railways, see Subject-Index of Minutes of Proceedings Inst. C.E., under—

"Railways, Inclines and mountain railways.
,, Motive power for steep inclines."

Also, see "Bibliography of papers relating to the working of steep inclines, &c.," in Minutes of Proceedings Inst. C.E., vol. xcvi. p. 141.—SEC. INST. C.E.

TABLE GIVING PARTICULARS OF VARIOUS MOUNTAIN RAILWAYS.

	1	2	3	4	5
Name	Ceylon Government Railway, Kadugannawa Incline.	New South Wales Government Railway.	Indian State Railways.	Cape Government Railway, Africa.	St. Gothard Railway (Mountain Section).
System	Adhesion.	Adhesion.	Adhesion.	Adhesion.	Adhesion.
Gauge	5 feet 6 ins.	4 ft. 8½ ins.	5 feet 6 ins.	3 feet 6 inches.	4 ft. 8½ ins.
Cost of construction, per mile	..	..	..	..	£68,873 (exclusive of summit tunnel).
Radius of sharpest curve, metres	201·16	..	..	100·00	300
„ „ feet	660	..	..	328	983
Steepest gradient	1 in 45	1 in 40	1 in 40	1 in 40	1 in 37
Length of incline	12 miles.	..	..	Various.	..
Diameter of cylinder	17 inches.	20 inches.	19 inches.	17 inches.	15¾ & 22⅝ ins.
Stroke	26 „	26 „	26 „	23 „	25¼ inches.
Axles, number	3 all coupled.	5 (three coupled)	6 (coupled in threes).	4 coupled and 2 bogie.	6 (coupled in threes).
Rigid wheel-base	9 feet 6 ins.	13 ft. 10 ins.	..	12 feet.	8 ft. 10 ins.
Diameter of wheels	3 „ 6 „	5 feet.	4 feet 2 ins.	3 feet 6½ ins. and 2 feet 4 ins.	4 ft. 0 ins.
Heating-surface	1,342 sq. feet.	1,922 sq. feet.	1,382 sq. feet.	1,000 sq. feet.	1,660 sq. ft.
Engine weight (loaded)	32·5 tons.	56·75 tons.	87·10 tons.	45·1 tons.	84 tons.
Tender weight (loaded)	19·0 „	31·75 „	40·90 „	29·16 „	..
Gross load of wagons and freight hauled up the incline	147 „	275 „	450 „	..	200 „
Exceptional ditto	..	..	..	..	220 „
Load drawn per ton[1] of locomotive weight	2·85 „	3·1 „	3·5 „	..	2·38 „
Exceptional ditto	..	..	..	..	..
Builders of engine	..	Messrs. Beyer, Peacock & Co.	Messrs. Neilson.	Messrs. Neilson.	T. A. Maffei.
Type „	A	..	D	B	X (Mallet compound).

[1] The locomotive weight here includes the weight of tender.

TABLE GIVING PARTICULARS OF

	6	7	8	9
Name	Darjeeling Railway, Himalayas.	La Guaira-Caracas Railway, Venezuela.	Mexican Railway, Mexico.	Callao-Oroya Railway, Peru.
System	Adhesion.	Adhesion.	Adhesion.	Adhesion.
Gauge	2 feet.	3 feet.	4 feet 8½ ins.	4 feet 8½ ins.
Cost of construction, per mile	£4,575	£25,000	..	£31,960
Radius of sharpest curve, metres	21·33	42·67	100	120
" " feet	70	140	328	394
Steepest gradient	1 in 28	1 in 27	1 in 25	1 in 25
Length of incline	40 miles.	23 miles.	14 miles.	100 miles.
Diameter of cylinder	11 inches.	15½ inches.	16 inches.	18 inches.
Stroke	14 "	20 "	22 "	24 "
Axles, number	2 coupled	3 coupled and 1 bogie.	6 (coupled in threes).	..
Rigid wheel-base	5 feet 6 ins.	6 feet 10 ins.	8 feet 3 inches.	14 ft. 9 ins.
Diameter of wheels	2 " 2 "	3 feet.	3 " 6 "	4 ft. 1 inch.
Heating-surface	355 sq. feet.	872 sq. feet.	1,712 sq. feet.	1,066 sq. feet.
Engine-weight (loaded)	13·75 tons.	33·75 tons.	92·25 tons.	45 tons.[1]
Gross load of wagons and freight hauled up the incline	35 "	68 tons.	175 tons.	75 "
Exceptional ditto	..	90 "	210 "	..
Load drawn per ton of locomotive weight	2·5 "	2·02 "	1·90 "	1·15[1] "
Exceptional ditto	..	..	2·28 "	..
Builders of engine	Messrs. Sharp, Stewart.	Messrs. Beyer, Peacock.	Messrs. Neilson.	Rogers Loco. Co., Patterson, U.S.A.
Type "	C	F	G	..

[1] Approximate only. The approximate weight of the tender is 20 tons.

VARIOUS MOUNTAIN RAILWAYS—*continued.*

10	11	12	13	14
Landquart-Davos, Switzerland.	Yverdon-St. Croix, Switzerland.	Hartz Railway, Brunswick.	Mostar-Serajevo Railway, Bosnia.	Tiadaghton-Fahnastalk, Pennsylvania, U.S.A. (Switch-back).
Adhesion.	Adhesion.	Adhesion and Abt rack combined.	Adhesion and Abt rack combined.	Adhesion.
1 metre.	1 metre.	4 ft. 8½ inches.	2 feet 6 inches.	4 ft. 8½ inches.
£11,520	..	£10,458	..	..
100	100	200	125	58
328	328	656·18[2]	410	191
1 in 22·2	1 in 22.	1 in 16·6	1 in 16·6	1 in 16·6
13·7 miles.	..	4⅓ miles of rack.	Length, 6·7 miles and 12 miles of rack.	One of 2·67 miles and various others.
G^3 13·4 ins.; G^4 19·3 & 13 ins.	11 and 16¾	Adhesion, 17·7 inches; rack, 11·82 inches.	Adhesion, 13⅜ inches; inside, 11⅞ inches.	Three of 12 inches each.
G^3 19·7 ins.; G^4 21·7 ins.	19¾	Adhesion, 23·62 inches; rack, 23·62 inches.	Adhesion, 17¾ inches; inside, 14½ inches.	10 inches.
G^3 3 coupled and 1 trailing; G^4 2 pairs of 2 coupled each.	4 coupled.	3 all coupled and 1 trailing, Bissel.	3 coupled and 1 trailing radial.	4 coupled (gearing 1 to 2).
G^3 7 ft. 10½ ins.; G^4 5 ft. 3 ins.	4 ft. 7 ins.	10 feet.	7 ft. 8 ins.	4 ft. 2 inches.
3 ft. 3 inches.	3 ft. 3½ ins.	6 of 4 ft. 1 in.; 2 of 2 ft. 5½ ins.	2 ft. 7½ ins. (6).	..
G^3 667 sq. ft.; G^4 863 sq. ft.	731 sq. ft.	1,463 sq. feet.	763 sq. ft.	..
G^3 30 tons; G^4 40 "	34 tons.	56 tons.	30·5 tons.	35 tons.
G^3 45 tons; G^4 70 "	60 "	120 "	70 "	0·75 ton (175 tons down).
..	..	150 "	75 "	..
G^3 1·5 ton; G^4 1·75 "	1·72 ton.	2·14 "	2·30 "	2·14
..	..	2·68 "	2·46 "	..
G^3 Winterthur; G^4 Maffei, Munich.	Grafenstaden works.	Maschinenfabrik Esslingen.	Floridsdorf.	Lima Loco. Co., Lima, Ohio, U.S.A.
G^3 Mogul; G^4 (Mallet compound).	V (Mallet compound).	H	I	Shay-geared locomotive.

[2] See p. 145.

TABLE GIVING PARTICULARS OF

	15	16	17	18
Name	Madison and Indianapolis, United States.	Indian State Railways.	New Zealand Railway, Rimutaka incline.	Eisenerz-Vordernberg, Styria.
System	Adhesion.	Adhesion.	Centre rail. Fell tank engine.	Adhesion and Abt rack combined.
Gauge	4 ft. 8½ ins.	5 feet 6 inches.	3 ft. 6 inches.	4 feet 8½ inches.
Cost of construction, per mile	..	..	£28,160	£45,160
Radius of sharpest curve, metres	..	..	100·61	180
„ „ feet	..	500	330	590·56
Steepest gradient	1 in 16·5	1 in 15·5	1 in 15	1 in 14·7
Length of incline	1⅓ miles.	..	2½ miles.	9 miles of rack.
Diameter of cylinder	20½ inches.	18 inches.	Adhesion, 14 inches; centre rail, 12 inches.	Adhesion, 18·89 inches; rack, 16·54 inches.
Stroke	24 „	26 „	Adhesion, 16 inches; centre rail, 14 inches.	Adhesion, 19·68 inches; rack, 17·71 inches.
Axles, number	4 coupled.	4 all coupled.	2 coupled & 1 trailing.	3 coupled and 1 trailing, Bissel.
Rigid wheel-base	..	14 feet 3 ins.	..	11 feet 5 inches.
Diameter of wheels	3 ft. 6 ins.	4 feet.	4 of 1 ft. 10½ ins. (centre rail); 4 of 2 ft. 8 ins.; 2 of 2 ft. 6 ins.	3 ft. 5 inches.
Heating-surface	1,378 sq. feet.	1,244 sq. feet.	974 sq. feet.	1,560 sq. feet.
Engine weight (loaded)	50 tons.	59·15 tons.	36 tons.	55 and 59 tons.
Gross load of wagons and freight hauled up the incline	137½ tons.	54 tons.	63 „	110 „
Exceptional ditto	..	..	70 „	..
Load drawn per ton of locomotive weight	2·75 „	0·91 ton.	1·67 „	2·00 „
Exceptional ditto	..	..	1·71 „	..
Builders of engine	Jeffersonville, Madison and Indianapolis RR. Co.	Messrs. Neilson.	Messrs. Neilson.	Floridsdorf.
Type „	..	E	J	H

VARIOUS MOUNTAIN RAILWAYS—*continued.*

19	20	21	22	23
Puerto Cabello-Valencia, S.A. Trincheras incline.	Oertelsbruch Railway, Saxe Meiningen.	Padang, Sumatra.	Cantagallo Railway, Brazil.	São Paulo Railway, Santos incline, Brazil.
Abt rack.	Adhesion and Abt rack combined.	Riggenbach rack.	Adhesion.	Cable.
3 feet 6 inches.	4 feet 8½ inches.	3 feet 6 inches.	1·10 metre.	5 feet 3 inches.
..	..	£11,400	£20,000	..
125	150	150	40	301·75
410·11 1 in 12·5	492·13 1 in 12·5	492 1 in 12·5	131·23 1 in 12	990 1 in 9·75
2¼ miles.	1 mile of rack.	19 miles of rack.	6¼ miles.	5 miles of inclines.
11¼ inches (4).	11·81 inches.	13·4, 17 and 17.	18 inches.	26 inches.
18 inches.	Adhesion, 19·68 inches; rack, 15·75 inches.	19·7 inches.	20 "	5 feet.
3	2 coupled and 1 trailing, Bissel.	2 coupled and 1 trailing, 2 coupled.	3 coupled.	..
8 feet 9 inches.	6 feet 6¾ inches.	6 ft. 7 inches, 9 ft. 2 ins. & 8 ft. 2 inches.	8 feet 3 inches.	..
3 feet 6 ins.; 2 feet 1 9/16 in. pinions.	4 coupled of 35·4 ins.; 2 trailing of 29·5 inches.	3 feet 3 ins.	3 feet 3 inches.	..
1,167 sq. feet.	517 sq. feet.	863, 711 and 614 sq. feet.	..	..
40·3 tons.	23⅕ tons.	26·25, 21·61 & 20·9 tons.	40[1] tons.	4 stationary engines of 150 HP. nominal each.
67 "	50 "	60, 40 & 40 tons.	40 "	40 tons.
95 "	..	..	..	..
1·66 "	2·17 "	2·3, 1·85 and 1·91 tons.	1 ton	..
2·35 "	..	..	..	..
Messrs. Beyer, Peacock.	Winterthur Works.	Esslingen Works. *h* and *i*.	Messrs. Baldwin.	..
K	..	..	..	..

[1] See p. 122.

TABLE GIVING PARTICULARS OF

	24	25	26
Name	Visp-Zermatt Railway, Switzerland.	Diakophto Railway, Greece.	Montserrat Railway, Spain.
System	Adhesion and Abt rack.	Adhesion and Abt rack.	Abt rack.
Gauge	1 metre.	0·75 metre.	1 metre.
Cost of construction, per mile . . .	£7,150	..	..
Radius of sharpest curve . . metres	80 [1]	50·00	65
„ „ „ feet	262·47	164·04	213·25
Steepest gradient .	1 in 8	1 in 6·9	1 in 6·6
Length of incline .	4 miles of rack.	2½ miles of rack.	4·88 miles of rack.
Diameter of cylinder	Adhesion, 12·6 inches; rack, 14·17 inches.	Adhesion, 9·45 inches; rack, 8·66 inches.	12 inches.
Stroke	Adhesion, 17·71 inches; rack, 17·71 inches.	Adhesion, 13·39 inches; rack, 19·69 inches.	22 „
Axles, number . .	2-coupled and 1 trailing.	3-coupled and 1 trailing.	2-coupled and 1 trailing.
Rigid wheel-base .	6 feet 5 inches.	6 feet 2¾ inches.	4 feet 8 inches.
Diameter of wheels .	3 feet.	Coupled 23·6 inches; trailing, 19·69 inches.	4 of 2 ft. 2 ins.; 2 of 1 ft. 8½ ins.
Heating-surface . .	697 square feet.	308 square feet.	355 sq. feet.
Engine weight (loaded)	29 tons.	15·6 tons.	17 tons.
Gross load of wagons and freight hauled up the incline . .	45 „	16 „	24 „
Load drawn per ton of locomotive weight	1·55 „	1·02 „	1·41 „
Builders of engine .	Winterthur Works.	Messrs. Cail.	Messrs. Cail.
Type „ .	..	..	L

[1] There is also a curve of 60 metres radius in Visp station. The

VARIOUS MOUNTAIN RAILWAYS—*continued.*

27	28	29	30	31
Rüdesheim-Niederwald, Germany.	Revard Railway, France.	Generoso Railway, Switzerland.	Pike's Peak, Colorado, United States.	Rothhorn Railway, Switzerland.
Riggenbach rack.	Abt rack.	Abt rack.	Abt rack.	Abt rack.
1 metre.	1 metre.	0·80 metre.	4 ft. 8½ ins.	0·80 metre.
..	..	£12,872	£11,409	£17,684
300	75	60	115	60
984	246·07	196·85	377·30	196·85
1 in 5	1 in 4·76	1 in 4·5	1 in 4	1 in 4
1·5 miles of rack.	5·7 miles of rack.	5·6 miles of rack.	8·75 miles of rack.	4·72 miles of rack.
12·2 inches.	12 inches.	11·81 inches.	17 inches.	11·81 inches.
19·7 „	20 „	21·65 „	20 „	21·65 „
2 trailing.	2-coupled.	3 (two pinion-axles).	3 (two pinion-axles).	3 (two pinion-axles).
6 ft. 7 inches.	..	4 feet 1 in.	..	4 ft. 7½ inches.
2 ft. 4 inches, adhesion; 2 ft. 10 ins. pinion.	..	Pinions, 23·6 ins.; wheels, 26·8 inches.	25·5 inches.	Pinions, 23·6 ins.; wheels, 26·8 inches.
500 sq. feet.	..	344 sq. feet.	..	400 square feet.
16·75 tons.	17 tons.	14·5 tons.	23·8 tons.	17·5 tons.
14·2 „	10 „	9 „	18·7 „	8·5 „
0·85 „	0·59 „	0·62 „	0·78 „	0·49 „
Esslingen Works. *b*	Winterthur Works. L	Winterthur Works. L	Baldwin Co. ..	Winterthur Works. L

80-metre curves do not occur where the rack is laid.

TABLE GIVING PARTICULARS OF VARIOUS MOUNTAIN RAILWAYS—*continued.*

	32	33	34
Name	Vitznau-Rigi Railway, Switzerland.	Salzburg-Gaisberg Railway, Austria.	Schafberg Railway, Austria.
System	Riggenbach rack.	Riggenbach rack.	Abt rack.
Gauge	4 ft. 8½ ins.	1 metre.	1 metre.
Cost of construction, per mile	£26,208	£19,840	..
Radius of sharpest curve, metres	180	150	80
„ „ feet	590	492	262·47
Steepest gradient	1 in 4.	1 in 4.	1 in 3·9
Length of incline	4·2 miles.	3·42 miles of rack.	..
Diameter of cylinder	10⅝ inches.	12·2 inches.	..
Stroke	15¾ „	19·7 „	..
Axles, number	1 driving 1 trailing.	2 trailing.	3
Rigid wheel-base	..	8 ft. 10 inches; 7 ft. 8½ ins.	..
Diameter of wheels	2 feet 2 ins.	2 feet 4 inches, 2 „ 6 „ adhesion. 2 „ 4 „, 3 „ 2 „ pinions.	..
Heating-surface	452 and 517 square feet.	678 and 538 square inches.	..
Engine weight (loaded)	15½ and 16 tons.	23·84 and 17·62 tons.	17·3 tons.
Gross load of wagons and freight hauled up the incline	10½ tons.	12·8 and 9·53 tons.	10 „
Load drawn per ton of locomotive weight	0·7 „	0·54 ton.	0·57 „
Builders of engine	Olten and Winterthur Works.	Esslingen Works.	Krauss & Co.
Type „	..	*c*	L

(*Paper No. 2822.*)

"The Usui Mountain Railway, Japan."[1]

By Charles Assheton Whately Pownall, M. Inst. C.E.

The first railways made in Japan traversed the plains on the east coast between the sea and the central spine of mountains which runs down the whole length of the main island; their construction did not involve any heavy inclines except near Gotemba, at the base of Fujiyama, where the trunk line from Kobe to Tokio rises 1,400 feet in 14 miles with a maximum gradient, apart from compensation for curvature, of 1 in 40 extending for 6 miles without a break.

In order to make connection with the west coast, a line was constructed in 1881–84 from the north side of Lake Biwa to the sea at Tsuruga with the same ruling gradient. It then became necessary to take a line northward from Tokio to the west coast at Naoetsu, crossing the central range of mountains at the Usui Pass beyond Yokogawa. The railway through the plains on the east coast between Tokio and Takasaki was made first and was opened in 1884; in the following year the extension of 18 miles to Yokogawa, at the foot of the Usui Pass, was completed.

The section of 92 miles beyond the mountains, from Naoetsu on the west coast to Karuisawa at the summit of the Usui Pass, was next taken in hand and was finished at the end of 1888 with the same inclines. At that date the Pass remained as a gap which it was necessary to close in order to give through communication, and the problem it presented was very difficult to solve. In a direct line, the distance between Yokogawa at the base and Karuisawa at the summit is 5 miles, while the difference in level between the two places is 1,830 feet, or 366 feet per mile of country to be traversed. This rise of 1,830 feet is almost identical with the 1,840 feet on the St. Gothard railway between Amsteg and the entrance of the Göschenen tunnel; but there the horizontal

[1] The discussion upon this and the preceding Papers was taken together.
An article giving some particulars of the project, and of its execution appeared in *Engineering* of the 19th October, 1894.—Sec. Inst. C.E.

distance is 8 miles, which length the development of the railway increases to 15 miles and enables adhesion inclines of 1 in 38½ to be used. Between the points named, the Usui was more difficult than the St. Gothard railway on the section containing the famous spiral tunnels, in the ratio of 8 to 5; it was at first thought impossible to obtain the necessary development for an adhesion line worked by ordinary engines. Various other schemes were brought forward, in some of which switch-backs on an American plan were included; these, however, were set aside, as it was thought they would be difficult to work with the heavy traffic that was to be expected between the capital and the provinces on the north-west coast.

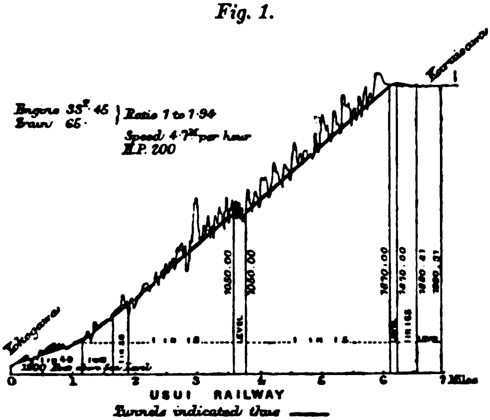
Before the construction of the railway, a large amount of rice and other produce was brought over the Pass to Tokio, whence foreign and manufactured goods were sent to the provinces by the same route; and after the completion of the Naoetsu-Karuisawa railway about three hundred people went over the Pass each way every day. It was anticipated that the opening of the railway throughout would largely increase this existing traffic, and the question was therefore not one of taking a line into the hills for tourist passengers only, nor of making a branch railway up to mines or quarries where heavy loads might be dealt with apart from the consideration of through working, but both passengers and goods had to be transported over the mountains from the plains on one side of the country to those on the other side, with the greatest possible uniformity in the service. In the summer and autumn of 1889, a fresh examination of the district was made, and, though the very rugged nature of the hills caused great difficulty in forming development loops, it was found possible to lay out a line on that principle with a maximum inclination of 1 in 40, compensated for curvature. The sharpest curves would have been of 10 chains radius, and the length of the line 15¼ miles to the top of the Pass; of this distance 4½ miles would have been in tunnel, but with no tunnel exceeding 43 chains in length, and with no heavy bridges or viaducts. The cost of the scheme was estimated at approximately $2,000,000—equal, at the then rate of exchange, to £300,000, or, say, £20,000 per mile.

The railway would have been constructed in this way had not favourable accounts been just then received of the combined rack-and-adhesion method of working the inclines on the Hartz mountains in Germany. As trains of 120 tons weight were there taken up inclines of 1 in 16½ at a speed of 7 miles an hour, it was thought that a load of at least 100 tons could thus be taken up 1 in 15 on the

Usui line at 5 miles an hour, and that this might suffice for the requirements. Meanwhile other projects for mountain railways in Japan were being brought forward, and it was considered desirable to try the Abt system at Usui as a possible precedent for other similar works; while it was hoped that economy would result from the length of the railway being reduced to 7 miles, and that a saving of $500,000 might thus be effected. A final survey was therefore made in the spring of 1890, and in October of that year it was decided to adopt the Abt system, with a rack incline of 1 in 15 for 5 miles, broken half-way by a passing-place to facilitate traffic by allowing a train to start from each end about every hour instead of at intervals of two hours.

Fig. 1 shows a section of the Usui railway, as made with two

Fig. 1.

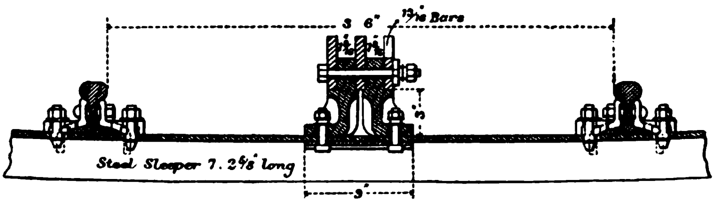


rack inclines, of which the lower is 2·45 miles, and the upper is 2·41 miles long. The upper incline is almost entirely in tunnel through the spurs of the hills along which the railway is carried, and it only emerges from tunnel when crossing ravines, some of which are of considerable depth. The aggregate length of the tunnels is 2·76 miles, and the longest one, on the lower incline, is 600 yards long. All the bridges and viaducts are built with brick arches, as it was feared that the effort of the pinion-wheel, exerted through the rack-rail, must force down-hill any girders on so steep a gradient. Subsequently on examination of the Hartz railway in Germany and of that between Eisenerz and Vordernberg in Austria, it was found that arches were always used for the under bridges; while on the Visp-Zermatt railway, where girders are put under the rack, the gradient is flattened so as to reduce this

pressure from the pinion. On the Usui railway the largest viaduct is one of four arches, each of 60 feet span, over the Usui river, a stream which runs in a gully so deep that the height from the base of the central pier to the rail-level is 109 feet.

These piers were specially designed to resist earthquake shocks in accordance with the formulas of Professor J. Milne, F.R.S., and could withstand an acceleration per second of 4 feet per second, or nearly 50 per cent. more than that which broke the piers of the Kiso bridge in the great earthquake in Japan of 1891. The construction of the line was begun in the spring of 1891 and was well carried out by Japanese engineers. Meanwhile the rack permanent way and four special locomotives to fulfil the required conditions had been ordered from Germany in October, 1890. This combined system consists in the addition to the locomotive of two pinion wheels, actuated by separate mechanism, which add to the tractive power by their grip on rack-bars fixed in the centre of the road.

Fig. 2.



Scale, ¾ inch to 1 foot.

The permanent way, which has been already fully described by Sir Guilford Molesworth,[1] was of 3 feet 6 inches gauge, and the form in which it is applied on the Usui line is shown in *Fig. 2*; this closely resembles the original pattern at the Hartz, except that the central chair which holds the rack-bars is fastened to the steel sleepers by bolts instead of by keys. When laying this permanent way, it is important that the lengths of the inside and outside rails on curves should correspond accurately with their radii; otherwise the rail-fastenings will not fit the steel sleepers whose distance apart is fixed by the rack-chairs in the centre of the road. The position of those chairs depends again on the lengths of the rack bars, and the pitch of the teeth in these bars governs all longitudinal distances. Care must be taken in ballasting that the sleepers are not packed in the middle, for if this is done they may rock and throw the three transverse points of support—

[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 491.

the two rails and the central rack-bars—out of a true line. The weight of the treble rack-bars, with their chairs and fastenings, was 100 tons per mile, and their cost, together with the steel sleepers, was £3,000 per mile, without freight or the expense of laying.

By the end of 1892 all the construction work on the railway was finished, and the expenditure up to the date of opening on the 1st of April, 1893, was officially returned as follows:—

	$	£
Surveys, superintendence and engineering	87,998	13,200
Right of way and station ground . . .	14,580	2,187
Stations.	8,000	1,200
Earth-works	106,000	15,900
Bridges, culverts and drain-pipes . . .	139,200	20,893
Tunnels.	753,851	113,077
Permanent-way	155,692	23,356
Rolling-stock, including four special engines	419,456	62,918
Machine-shop and buildings.	22,685	3,402
Conveyance of materials	264,471	39,670
Sundry items	19,239	2,866
Totals . . .	1,991,172	298,669

The second column above is derived from the first by taking the Japanese dollar at 3*s*., its average value while this work was in progress. In the above list the tunnels are the heaviest item, and their cost per lineal yard amounted to $155 or £23 5*s*. 0*d*., apart from the conveyance of materials, which comes under a separate heading, the large cost of which is to be accounted for by the very rugged nature of the country. The cost of constructing and equipping the railway amounted to almost £42,700 per mile.

At the beginning of 1893 the locomotives arrived, and they were at once erected and set to work on the line. The weight of each locomotive, distributed over three axles, giving a wheel-base of 11·8 feet, is 33·45 tons. The cylinders operating the driving-wheels, of which the three pairs (35·43 inches in diameter) are coupled together, are 15·35 inches in diameter and have a stroke of 19·68 inches. Those driving the pinion, which is 22·55 inches in diameter, are 13·38 inches in diameter and have a stroke of 15·75 inches. The fire-box and tubes together give a heating-surface of 807·11 square feet, the grate-surface being 18·5 square feet. The ratio of grate-surface to heating-surface is thus 1 to 43·5. The boiler-pressure is 170·7 lbs. per square inch. In consequence of the small heating-surface provided, the locomotives proved unable to take up the inclines more than two-thirds of what was expected, and

60 to 70 tons of train-load at 4·7 miles an hour has been the limit of their capacity in ordinary working. This represents 200 HP., and no greater power was exerted on one occasion when the load amounted to 100 tons, for the speed had then to be reduced to about 3 miles an hour. Owing to the deficiency of heating-surface, great difficulty was experienced in keeping steam to supply the four cylinders, especially at first and until it was explained that the steam should not be admitted fully and equally to both sets of cylinders on entering the rack section. The intention of the makers was that the pinion mechanism should be used as auxiliary to that for adhesion, which, with favourable weather, should be employed to its utmost extent; full steam to be first given to the adhesion-cylinders and steam to be afterwards supplied to the pinion-cylinders to the extent required to give the necessary power. When the weather is bad, the adhesion falls in amount, so that less steam is required for it and the bulk of the work is thrown on the pinion-mechanism which then takes the larger share of the steam.

In other mountain-railways worked with these combination-engines, one pair of cylinders is always used to supplement the other; though sometimes it is found that, instead of the pinion helping the adhesion, the adhesion is used to help the pinion which is first brought in to full action when on the rack. After this explanation was received better results were obtained, but so far the performance corresponds almost exactly with that of the Fell engines on the Rimutaka incline in New Zealand, as described by Mr. J. P. Maxwell[1] in 1880. There the gauge, 3 feet 6 inches, is the same, the continuous incline of 2½ miles on 1 in 15 is identical with the Japanese line, while the 36-ton engine took a load of 63 tons. The present 34-ton engines of the Usui line are worked with a strong forced draught in order to obtain as much steam as possible, and this causes an excessive amount of smoke—a great annoyance in the numerous tunnels, up which the smoke rises. The engine is always below the train. As the speed is so slow the train cannot run away from the smoke, which follows and overtakes it when the wind is blowing up the valley. In the discussion on Mr. Maxwell's Paper it was stated by Mr. J. Carruthers[2] that the same trouble had arisen from the steam of four-cylinder engines in the New Zealand tunnels.

Four passenger- and five goods-trains have been taken daily up

---

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 50.
[2] *Ibid*, vol. lxiii. p. 86.

and down the Usui Pass during the first year's working without the occurrence of any accident; the running of the pinions in the rack is so smooth that when on the footplate it is hard to realise that any special mechanism is at work below. The existence of the rack enables valuable brake-power to be obtained on the descent, for which, besides hand-brakes on the engine and the Automatic Vacuum-brake through the train, special brake-power is furnished by the cylinders being used as air-compressors. Although it is partly due to the narrow gauge that the heating-surface of the present Usui engines is but half that of the Hartz engines, no doubt is entertained that more powerful engines than those in use can be obtained for a 3-foot 6-inch gauge. An order has accordingly been given for other engines with 50 per cent. more heating-surface and an additional axle on a Bissel truck under the footplate, by which another 12 tons can be carried. This will bring the weight of the engine up to 46 tons, and that of the train is then expected to be 100 tons, a ratio of 1 to 2·17 between engine and train, instead of the present ratio of 1 to 1·94. It is hoped also that the new engines will consume the fuel more thoroughly and with diminished draught, so that the ventilation of the tunnels may be improved by a reduction of the smoke produced.

General Considerations.

When considering the problem of the Usui Railway, it was necessary for the Author to study what had already been done on mountain-railways which deal with heavy traffic, especially where the rack or rack-and-adhesion systems had been adopted. In the autumn of 1893 the Author visited several such lines on the Continent of Europe, and to the kindness with which he was received by the engineers in charge of them, and their readiness to afford both information and facilities for inspection, the following notes are due. He proposes to divide five railways, on which he will make a few comparative observations, into two classes. (1) The Hartz and the Eisenerz on normal gauge. (2) The Usui, the Mostar, and the Visp-Zermatt lines on smaller gauges. Particulars of the Hartz, Eisenerz, Mostar and Visp-Zermatt railways are given in the Appendix to the Paper on the Monistrol-Montserrat Rack-Railway," by Alfred Collett, M. Inst. C.E., *ante*, pp. 31–34.

In the first class, the ratio of engine-weight to that of the train is the same, 1 to 2·14; the speed is a little greater and the gradient a little less on the Hartz than on the Eisenerz line;

the mean speed is 6·67 miles an hour on the rack, of which the mean maximum incline is 1 in 15·6.

In the second class, omitting the Zermatt line from the comparison. the ratio of engine-weight to train-weight is 1 to 1·94; on the Usui and the Mostar lines, the speeds are 4·7 miles and 5 miles an hour, giving a mean of 4·85 miles; and the inclines are 1 in 15 and 1 in 16·6, of which the mean is 1 in 15·8, a trifle less than in the first class.

Combining the two classes, on the normal gauge the engines draw a little more, and on the narrow gauge a little less, than twice their own weight on an average incline for all the four railways of 1 in 15·7. It has been recorded[1] that 1 in 15 is the limiting incline on which an engine will draw a load equal to its own weight by adhesion alone, and so the addition of the pinion mechanism doubles the haulage-power on such inclines. An incline of 1 in 15 is, however, regarded by some of the engineers on the Continent who are best qualified by experience to give an opinion, as too steep for profitable working even with the rack, and in Austria—where this system has been much studied—a Government regulation prescribes 4½ per cent., or 1 in 22½, as the maximum for combination railways; and there appears to be a general disposition to reduce the rate of inclination from that first attempted, at the same time increasing the weight and power of the engines so as to be able to take heavier loads. Thus, a new railway from Klangenfurt to Krainburg is proposed with inclines of 1 in 22½, and with engines of 65 tons weight which are intended to draw trains weighing 162 tons.

In comparing the results obtained by combination-engines with those of adhesion-working, it has been stated in a Paper[2] by Messrs. Bock and Abt, that on the 1 in 40 adhesion-inclines over the Alps, the average ratio of engine-weight to that of the train is about 1 to 2·2. Such a ratio, if taken alone, would mean that only 10 per cent. more load could be drawn on 1 in 40 by adhesion than on 1 in 15 by combined rack-and-adhesion; but it is necessary to include also the factor of speed, which is almost always higher on an adhesion line than where a rack is used. From Amsteg up to Goschenen on the St. Gothard Railway, the speed is 11·7 miles an hour; on the Mont Cenis line it is 11·9 miles in running up from Oulx to Bardonnechia. On the Brenner incline[1] a load of

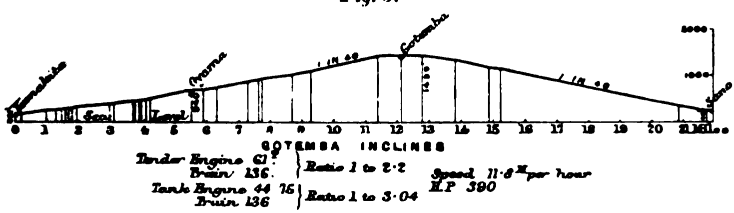
---

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. pp. 55, 104; vol. xcvi. p. 160.
[2] Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines, 1888, pp. 83, 94, 107.

150 tons is hauled at 9 miles an hour, or a passenger train weighing 120 to 130 tons, at 14 miles an hour. In New South Wales,[2] on 4 feet 8½ inches gauge, a train of 284 tons weight has been taken up an incline of 1 in 40 at a speed of 12 miles an hour by a tender-engine weighing 93½ tons.

On the heavy adhesion inclines at Gotemba in Japan, *Fig. 3*, with which the Author has been familiar since their opening in 1889, the speed on the ascent is the mean of that at St. Gothard and Mont Cenis, viz., 11·8 miles an hour; and at that rate trains of 136 tons weight, exclusive of the engine, are hauled up long inclines which are nominally 1 in 40, but are really equal to 1 in 37 when the resistance due to curvature is taken into account. In taking this load the work done is equal to 390 HP. The above is the working load, as on the Hartz line a heavier train (weighing 200 tons) has been taken at a reduced speed; but in order to obtain a comparison, the ordinary loads are given in each case. At Gotemba the work is done partly

Fig. 3.



by English and partly by American engines, all of modern construction and built by the best makers. Their performances and conditions of service are the same, but the first cost of the American engines is 10 per cent. more than that of those from England, and they burn 72·64 lbs. of coal per mile, while the English tender-engines burn 55·04 lbs., and the tank-engines burn 49·6 lbs. per mile. The ratios of engine to load are: for the American engines 1 to 2·2, for the English tender-engines 1 to 2·5, and for the English tank-engines 1 to 3·04.

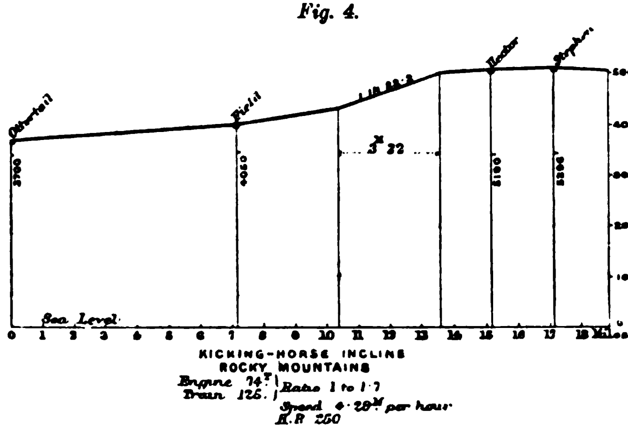
When other conditions—such as siding-accommodation and distances between block stations—are equal, the amount of traffic that can be taken over a line in one day depends just as much on the speed of running (which determines the number of

---

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 132.
[2] *Engineering*, May 13th, 1892, p. 585.

trains that can be passed in a day) as on the weight of the individual train; and so the product of speed and tons of weight may be called "speed-tons" and may be used as a measure of the traffic-capacity of different lines when comparing them. From the above figures the average of the Hartz and the Eisenerz railways is 118 × 6·67 = 787 "speed-tons," and at Gotemba, with a gauge of 3 feet 6 inches, the product is 136 × 11·8 = 1,604 "speed-tons." If a new railway were contemplated elsewhere, with either of the above as precedents, the length of line to be constructed, with adhesion only or with rack-and-adhesion, between two places at different elevations, would be in the ratio of the maximum gradients, that is as 37 to 15·6, *i.e.* as 2·4 to 1. But the value of the adhesion line for traffic purposes would be to that of the rack-

Fig. 4.



and-adhesion system as 1,604 to 787, *i.e.* as 2·04 to 1. The adhesion line would therefore be nearly two-and-a-half times as long as the other; but it would take more than twice the traffic of the other, and both the increased cost of the permanent way and the inconvenience, if on a through line, of keeping special engines would be avoided. It does not appear, then, that the normal-gauge rack-and-adhesion can compare favourably even with a narrow-gauge adhesion line when the inclination of the latter is not much more than the usually recognised limit of 1 in 40. But when that limit is exceeded, the advantage of the adhesion decreases very rapidly, and the comparison works out differently; the 1 in 22·2 adhesion incline of the Canadian Pacific Railway at the Kicking-Horse Pass on the western slope of the Rocky Mountains may be taken as an instance of this. A section of the incline is shown in

Fig. 4. In a Paper by Mr. G. C. Cuningham,[1] M. Inst. C.E., it is stated that a load of 125 tons was taken up the incline at 4·29 miles an hour. This would give 536 "speed-tons"; but in July, 1893, when the Author passed over the line in weather most favourable for adhesion working, three of the special heavy engines on one train failed to take an average load of 114 tons per engine at about the speed mentioned, and the train came to a standstill five minutes after it began the ascent.

Accepting the 536 "speed-tons" deduced from Mr. Cuningham's figures, the traffic-capacity of this link in the Canadian Pacific Railway is to the average of the Hartz and the Eisenerz lines, on the same gauge, as 536 to 787, or as 0·68 to 1; while the lengths of similarly built new line for the same unit of ascent would be to one other as 22·2 to 15·6, *i.e.* as 1·4 to 1; giving an ultimate ratio of 1·4 to 0·68, or an advantage of more than two to one, in favour of the combined system when compared with a very steep adhesion gradient on what is essentially a through line.

Each case must be considered on its merits. It will not always follow that a severe though short incline which plunges directly into the centre of a mountainous district, can be executed at the same cost per mile as an easier adhesion incline winding round the hills; but, even if that should be so, the saving in length of construction may be balanced by the reduction in traffic-capacity caused by slower speed as well as by lighter trains. When a gradient of about 1 in 40 cannot be obtained for an adhesion line, the value of combined rack-and-adhesion begins to be perceptible, and the field for its future use with heavy traffic probably lies on gradients between 1 in 35 and 1 in 20. In such cases, the addition to the cost of the permanent way that it involves will be more than compensated by the heavier loads which can be hauled by its means, and by the great security which the pinion-brake gives in the descent compared with that afforded by adhesion-brakes only.

The Paper is accompanied by two tracings and a photograph, from which the *Figs.* have been prepared.

---

[1] Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 115.

[DISCUSSION.

Discussion.

Sir Douglas Fox. Sir DOUGLAS FOX, Vice-President, was sure it would be the wish of the members that the thanks of the Institution should be heartily accorded to the Authors of the Papers. The subjects on which they treated were most instructive, not only as dealing with rather exceptional features, but also because they related to various parts of the world, and showed how the same principles had, in the several cases, and by different engineers, been practically applied to overcome similar difficulties.

Mr. Collett. Mr. ALFRED COLLETT mentioned that his special object in writing the Paper had been to show the load hauled by different classes of mountain engines in actual practice on various gradients. It had come under his notice that some engines hauled less than they were calculated to haul, a result due to want of steam, to too small heating-surface, and to other reasons. He thought it would be of interest to give a Table of the principal dimensions used on mountain railways and engines in different parts of the world. They consisted of ordinary adhesion engines, Fairlie engines, and the Abt, Riggenbach, Fell, and wire-rope systems. He had carefully collected details as to the loads actually hauled, and the weights of the engines, calculating their ratio, of which the Table on p. 29 gave a few examples. The 1 in 28 gradient referred to the Darjeeling Railway, and the 1 in 16·7 gradient to the Hartz Railway, having an engine of a similar type to that at Eisenerz. The 1 in 12·5 referred to the Trincheras incline of the Puerto Cabello Railway, the engine having four cylinders, all working on the pinion-wheels. The 1 in 8 referred to the Visp-Zermatt Railway, on the Abt system. The 1 in 4 referred to the Pike's Peak Railway in Colorado, using an engine similar to the Montserrat engine. He hoped that points of haulage and gradients might be specially taken into account in the discussion.

Sir Guilford Molesworth. Sir GUILFORD MOLESWORTH observed that the Papers covered a somewhat wide field, reaching as they did from avalanches down to rack- and rope-traction. It had been stated by Mr. Berg that almost all risk of the occurrence of avalanches might be disregarded on a well-wooded hillside. This statement did not accord exactly with his experience. He had seen in the Himalayas traces of huge avalanches through the forests, leaving tracks

Sir Guilford Molesworth.

50 or 60 feet wide, and at the bottom of the valley a huge pile, perhaps 30 feet high, of shattered trunks of trees. In the Rocky Mountains and on the Central Pacific Railway snow-sheds were put up, some of them very strong and expensive, extending for considerable distances—nearly half a mile in length. The distances between reverse curves had been referred to by Mr. Berg. The Ceylon incline of 1 in 45 afforded a good object lesson. He had ordered that there should be a certain length of straight between each reverse curve. In one instance it was inadvertently lessened. One of the trains going up the incline fell short of water. The driver, who was new to his work, wanted to go on and fetch water. He uncoupled his engine, backed upon the train, setting it in motion, with the result that it went 6 miles down the incline, over a succession of reverse curves of 660 feet radius, until the end of the train was switched off at the very point where the length prescribed had been curtailed. He had used steel transverse sleepers, and found them extremely satisfactory. The general tendency was, however, to use too light sleepers with the idea of saving metal. There should not be for the ordinary gauge less than a certain weight, say 1½ cwt. for each of the sleepers, which should be strengthened, and not stamped out of simple flat plates, but out of rolled plates thickened up where the fastenings would come. There was one point with regard to mountain railways which he wished to emphasize. It was a common practice of engineers to place culverts on side-long ground at the bottom of the ravines. The plan he had adopted on the Ceylon incline was to run the culverts on the contour of the ground with a fall not steeper than 1 in 50 or 60, although the bottom of the ravine might fall about 1 in 4 or 5. The rocky nature of the country enabled this to be done very easily. Out of ninety-seven culverts on the Ceylon incline, of a length of 12 miles, there were only three that could not be dealt with in that way, and they all proved very satisfactory. This arrangement not only effected a large saving in the length of the culvert, but also lessened the destructive rush of water on the masonry. In one case he had put in a 20-foot culvert, throwing the outlet into another ravine, so as to take it right away from the toe of the embankment. The outlet was generally arranged so as to spill over rock. There could be no hard and fast way of dealing with mountain railways. There was the ordinary adhesion system; the adhesion with the corkscrew or spiral curve, which was generally a very expensive one, although the ground might in some cases lend itself to this mode of construction. The zigzag system

Sir Guilford Molesworth. was open to the great objection of over-running its zigzags, as was done in the case of the Bhore Ghat. Then there were the rack, the rope, and electrical systems, each having its particular merits and being adapted to different conditions. In the case of the Ceylon Railway the question of rope inclines was carefully considered. It was found from careful surveys that the character and features of the country were such that nothing was gained in length by the use of the rope incline system, and that in first cost it was the more expensive. The rope inclines were therefore abandoned, and the railway constructed with an incline of 1 in 45 for ordinary adhesion. On the St. Gothard Railway the locomotives were placed in the rear of the train, as stated by Mr. Berg, a practice usually adopted on Alpine railways, and also in the United States. For his own part, he considered this arrangement the safest for continuous inclines, because if both engines were placed in front, the strain on the draw-bars was exceedingly great. The train was apt to part, and then there was nothing to prevent the escape down the incline of that part of the train behind which the couplings had parted. In descending the incline it was of course necessary to place the engines in front. For pushing, it was desirable to adopt an automatic signal, actuated by compression of the buffers, so that the driver on each engine could see whether he was doing more or less than his proper share of the work. The more powerful incline-engine should be placed in front, and the ordinary engine, which brought the train up to the foot of the incline, behind. On the Ceylon Railway an object lesson was afforded from the fact that, as the train was going round a sharp curve it ran into a slip. The engine-driver behind did not see what was going on in front of the train which was out of sight. This happened before the automatic signals were adopted. The driver of the pushing engine went on, put on more steam, but the only result was, the engine and train were stopped, and no harm was done.

It was not desirable to have the second engine behind if there was any part of the line on which the gradient might be the reverse way of the general inclines. In some cases there might be an incline, on which, to overcome some difficulty, a portion of the incline was the reverse way. Of course, there was a danger in having the engine behind in such a case. It was therefore desirable, if it could possibly be arranged, to have the incline continuous, and as nearly as possible one steady gradient. The use of continuous brakes was sometimes found to be a difficult matter for working inclines. Foreign

Sir Guilford Molesworth.

stock came over the line, and in some cases the goods stock was not fitted for a continuous brake. The system which was adopted in Ceylon, and on some of the Indian State Railway inclines, was to use weighted brakes, which were found very effective. A weight of 56 lbs. was hung on the levers of the brake wagons, and the vibratory motion of the levers enabled the wheels to rotate slightly, so that they never skidded. The plan adopted was to weight the brakes to such an extent at the top of the incline, that it required a slight draw of the engine to start the train; then the engine brakes, and also the brake-van brakes, were in reserve in case of emergency. The Ceylon line was worked for twenty-eight years in that way most satisfactorily. The usual number of loaded wagons taken down was twenty-four. As many as forty had been taken in one train, but that was against orders, and it was undesirable to take so many. On one of the Indian State Railways he had adopted what was termed a test incline, that was, a short piece of incline succeeded by a short piece of level, just sufficient to hold a train, before entering on the main incline. The object was, that in case of the train overpowering the engines, it could be stopped on the level. No difficulty was ever experienced in this respect on the Ceylon incline, but as the ground favoured that construction on the Holkar State Railway he had adopted it. In some cases catch sidings were put in, but it was questionable whether they might not be an element of danger. Perhaps on the Bhore Ghat, the catch-siding might be an element of safety, because the trains were made to come to a dead stop before passing, and if not, they were turned into the catch-siding. But if a train were to get beyond control and run away at a very high speed, the sudden reversal of the gradient and the rapid switching out would be very likely to wreck the train. The economic gradient for adhesion must vary according to the climatic conditions of the country. In India the adhesion was as a rule greater than in more temperate climates. On heated rails the grip was better, and for this reason a larger cylinder area than was generally desirable in ordinary engines could be adopted. Where the climate was cold, and subject to frost, there was greater difficulty. Mr. Mosse, who was engineer and general manager of the Mauritius Railway, which had a gradient of 1 in 27, fixed the limit of economic gradient for adhesion at 1 in 40. The German Railway Union also fixed 1 in 40 as the limit to which ordinary adhesion railways should go. Of course, an engine working simply by adhesion could surmount steeper gradients than that. On one of the temporary lines on the Khojak

Sir Guilford Molesworth. pass, in Beluchistan, a tender engine weighing about 70 tons had taken up a gradient of 1 in 22, something like its own weight, 70 or 72 tons.[1] This was, of course, not very economical working. On the Mexican Railway, with a gradient of 1 in 25, the 90-ton engines took up about 200 tons of loaded wagons. He believed that Mr. Collett had rather under-estimated the amount in the Appendix.[2] Sir Guilford Molesworth in 1886 had had occasion to inspect the Abt system, and was much struck with the satisfactory manner in which it was working on the Hartz Mountains. There was a gradient of 1 in 16½. When he went there the rails were covered with hoar frost, and a large amount of snow had fallen. The engine took the train up—about 130 tons of loaded wagons—very well indeed. He afterwards examined the wearing portions, and was gratified to find that the rack had not worn appreciably, while the pinions scarcely showed any wear. It was computed, from past experience of actual wear, that the pinions would last twelve years, and the racks something like a hundred years. He calculated that the efficiency of the rack-system in winter, where exposed to frost, with a coefficient of adhesion of one-eleventh, would, on a gradient of 1 in 40, be about two and a half times that of ordinary adhesion; with 1 in 25 about three times as efficient, and with 1 in 20 about three and three-quarter times as efficient as ordinary adhesion. That was of course taking a low coefficient for frost or sleet. The locomotive superintendent of the Brenner line had stated that the coefficient of adhesion diminished sometimes to one-fifteenth, or even one-twentieth. Of course the adhesion could be increased by sanding, but the sanding necessitated a large amount of wear of tires and rails. The Abt system was very convenient where there were steep gradients, combined with tolerably flat gradients, because the rack could be omitted and higher speed used where the gradient was not steep. An experiment had been made with the Abt system in India, but it had not been satisfactorily performed, being carried out in rather a perfunctory manner. Only a mile of railway had been laid, which was not sufficient to test it; secondly, the officer experimenting had taken a run at the gradient, getting up considerable speed before going on to it, and though the engines were only calculated for a speed of something like 7 or 8 miles an hour, they were run at something like 15 or 16

[1] Minutes of Proceedings Inst. C.E., vol. cxii. p. 311.

[2] The figures here referred to have been corrected in the Table, p. 36.—Sec. Inst. C.E.

Sir Guilford Molesworth.

miles an hour with both adhesion and rack-machinery in full blast. The result, as might naturally be expected, was that the steam ran short. As an example of the carelessness with which the experiments were conducted, on one occasion the officer in charge ran the engine on to the rack with the rack-gear in backward motion. There was a terrible jar, but wonderful to relate, no damage was done. He believed that a probable future of steep mountain railways would be high voltage electricity combined with the Abt rack.

With regard to rope-railways, the Hong Kong line, for passenger traffic only, had a maximum gradient of 1 in 2, with an average of 1 in 4, and an elevation of 1,200 feet. The braking was performed much in the same way as had been described by the Author. There was an automatic brake which acted if the guard relinquished his hold of a handle, and it was so effective that, on one occasion during experiments to see how quickly the train could be stopped, it was about a couple of hours before it could be got off again. On one of the lines in Beluchistan a temporary rope-line was constructed with several lifts, of 1 in $2\frac{1}{2}$ and 1 in $2\frac{3}{4}$.[1] The traffic that passed over it was about 45,000 tons as the maximum during a year, 6,000 tons as the maximum in a month, and 580 tons as the maximum in any one day. The yearly maximum was therefore less than a quarter of the rate of the daily maximum. The incline was used for temporary purposes, for passing materials, military and railway, during the construction of a tunnel. It was not for carrying passengers, and any handbrake would necessitate putting a man upon the car that went up and down, which he did not care to do. Any automatic hand-brake would probably lead to accident, and therefore he decided to do without a brake, giving strict orders that no one was to travel on the incline car. The incline worked several years satisfactorily until the tunnel was completed. The ideal section shown in *Fig. 11*, p. 12, on the Stanzerhorn cable-railway was a concave section, and though it might be theoretically better so far as giving equal load was concerned, he thought it was objectionable, as there was a great tendency for the rope to surge, and that surging action was dangerous where there was any curve on the incline; at all events it caused a great deal of wear to the rope. He would rather see a convex section, which kept the rope well down to the pulleys. Sometimes where there were concave sections it was necessary to keep the rope down by

[1] Minutes of Proceedings Inst. C.E., vol. cxii. p. 310.

Sir Guilford Molesworth. overhead pulleys. On the Hong Kong line there was an ingenious arrangement by which the rope was kept down. A pulley was attached to the car as it descended. When it got to a certain portion of the line it left the pulley on the rope, under a sort of bracket, keeping the rope down, and when the return car came up it caught up the pulley, and took it up again to the top.

Mr. Tomkins. Mr. W. S. TOMKINS said that practice in mountain railways, by which he supposed were meant railways having inclines steeper than 1 in 25, was very rare in this country. The northern heights of London were still accessible without a rack-railway, and there were not many of their mountains, except perhaps Snowdon, which presented sufficient attractions to justify the use of one. It therefore came about that the construction of these railways and the adaptation of means of working them, had fallen into the hands mainly of the Swiss Engineers, and they would all agree it had been very well done. Turning to ordinary practice, as he had said, the cases in which locomotives had to be considered for working rack railways had been very few in number; the greater part of their work was of course with adhesion engines, and, as those engines were very well known, he would only allude to two types which were in their way somewhat of a record. The one was the fine type of engine lately placed by Mr. Jones on the Highland Railway, which is a large ten-wheeled engine with 20-inch cylinders, and six coupled wheels for working heavy passenger trains over an incline of 1 in 40. The type was in this country unique. The other was the small engine illustrated in Mr. Collett's Paper for working the Darjeeling Railway, and certainly in its way quite a record, for it worked on a railway having a gauge of 2 feet only, and its record of work had shown that it drew per ton of its weight no less than 2·5 tons of load on an incline of 1 in 28. It presented a record equalled by no engine ever yet constructed, and so far as it went was an example of what might be done on a very cheap railway, constructed more or less on an ordinary road, working with very sharp curves and up steep inclines.

Mr. Carruthers. Mr. JOHN CARRUTHERS thought that the information contained in the Paper was all the more valuable because it came from many different parts of the world, and described the work of many different engineers who were engaged independently on the same problem, of how best to make a railway train climb a mountain side. He did not think, however, that all the conclusions that had been drawn from the data collected could be adopted. More

Mr. Carruthers.

especially was it difficult to admit, that the ratio so often mentioned between the load of the engine and the load of the train which it drew, was in any way a measure of the relative merits of different ways of constructing mountain railways. This very crude theory, even when modified, as Mr. Pownall had modified it, by bringing the speed of the train into the calculation, still led to conclusions that could not be accepted. For instance, Mr. Pownall deduced from his theory of speed-tons that had the Abt rack been put down on the Kicking-Horse incline, the efficiency of that incline would have been increased in the ratio of somewhat more than 2 to 1. Let two pairs of rails be considered, one with a rack and one without a rack, with engines developing the same HP. If it could be believed that one pair of rails would do twice the work of the other, he thought it went very far on the road towards a belief in perpetual motion. All theories of that sort seemed to be introducing very complicated and untrustworthy calculations into what was really a very simple matter. Whatever might be the style of traction employed, practically the same amount of work would be performed for a certain HP., unless there was some great mechanical imperfection in the machinery used, and certainly with either the rack, the Fell, or the rope systems, there was not such imperfection. Therefore there was nothing to do but to find out what HP. was developed in order to find what work could be got from it. For instance, with a uniform incline of 1 in 40 for 15 miles, a certain engine would take up a certain amount of goods in a certain time; but, if instead of making that uniform gradient the line was 10 miles along the level and then sprang the whole height in the remaining 5 miles, the same HP. being used, the top of the incline would be reached by the one road in exactly the same time as by the other with an equal load. It was a mere matter of calculating the power that was available. The only confusing element in the calculation was the weight of the engine itself, and of course the weight of the engine carried up was part of the work done. It was known that the weight of an engine must be heavy if the speed was high; that for a speed of 60 miles, an engine would draw much less than if the speed was reduced to 30 miles; in fact, the lower the speed the smaller the weight of engine required compared with that of the load. If, however, the speed was reduced below a certain amount the difficulty was met with that puzzled the first designers of the locomotive, that the adhesion was not sufficient to resist the thrust of the piston. On a steep incline the weight of the engine was always a

Mr. Carruthers. very important part of the weight of the train, and it often then became desirable to so reduce the weight of the engine, and therefore the speed of the train, that adhesion alone could no longer be used, but must be supplemented with the rack or with the Fell, the only two systems that need be discussed. Whatever system was adopted, for the same HP. the same amount of useful work would be obtained. His own experience was confined to two inclines, one the Rimutaka incline in New Zealand, of 1 in 15 worked by the Fell; the other, the Trincheras incline in Venezuela, 1 in 12½, worked by the rack system. Both were of nearly the same length, about 2 miles. As to these two lines, the engineers in New Zealand who had been working the line for the last sixteen years were enthusiastic believers in the Fell system, and said that the rack could not compare with it. On the other hand, in Venezuela, the men who were working on that incline insisted that the rack was far better than the Fell. He thought they might average those opinions and say that the two systems were equally successful. At all events, both inclines were working, and had been working for years, with great success, carrying heavy loads. There had been no accidents of any kind, no breakdowns, no delay of the traffic, and, in fact, the inclined parts of the lines were just as good and trustworthy as any other parts, so that there was no difficulty about them. His opinion of the two systems was that, for gradients up to 1 in 15 or 14, they were very nearly equal, with a preference for the rack where the curves were slight, that was to say, where there were no curves under 5 chains radius, with a preference for the Fell where the curves were sharper. He believed for those inclines they were both thoroughly good pieces of mechanism. Where the gradients exceeded 1 in 14, or 1 in 13, he should certainly prefer the rack. Comparing either of these systems with a longer adhesion gradient, there was not, mechanically, much to choose between them, and practically the same work would be done for the same power expended whichever system was used. That was shown by the fact that on the two inclines mentioned, and in many others all over the world, it was found from experience that the load carried up was just about what would be expected from the HP. developed by the engines. There must of course be the increased friction of the rack, but it was not a very serious matter. There must also be increased friction with the Fell system when the side wheels were pressed against the rail, but that was practically a matter that might be almost neglected. In comparing different systems it must always be assumed that

other conditions were equal, which was however very seldom the case. Where an adhesion incline was used, very often, and perhaps generally, it was necessary to increase the length of the line so as to get good gradients, and where that occurred undoubtedly the adhesion incline was mechanically at a disadvantage as compared with others. For instance, on the Usui line the distance from the bottom to the top by the direct line was 5 miles, but the line as surveyed, with a gradient of 1 in 40, would have been 15 miles. An extra length of 10 miles of road would have had to be constructed and maintained, and there would have been a mechanical drawback against the incline to the extent of the power required to draw the train 10 miles on the level in addition to what was required to take it up the incline. Therefore, undoubtedly, in that case the adhesion incline was not as good, theoretically, as the other, and the time required to get from the bottom of the incline would be less by the rack in proportion as the mechanical power required was less. Similarly on the St. Gothard line a great amount of extra length of line had to be built in order to get the incline, and it was done in a manner necessarily very expensive, viz., by corkscrew tunnels, and long loops up the tributary valleys. Had a steep incline been introduced, the St. Gothard Railway would have been shorter and far less costly, while the time required to pass from one side of the mountain to the other would have been less in proportion to the less mechanical power required to work the train; the maintenance of the line would have been less, and certainly the pleasure of travelling on it would have been very much greater. When the St. Gothard was built the rack system was in an experimental stage, and it would have required a good deal of courage on the part of engineers to adopt the rack. But if an engineer, laying out a line now across the St. Gothard, were to adopt the present alignment, he would be inexcusably giving the company for whom he was working a very much worse line for a much greater cost than if he had introduced the steeper incline. It had been stated by Mr. Pownall that he used brick arches for all viaducts on account of the inconvenience of the pressing downwards of girders on the incline. On the Trincheras incline, where the gradients were somewhat steeper—1 in 12½ against 1 in 15—there were five viaducts of considerable length, averaging 100 yards each, and no inconvenience had been found. The abutment on the down-hill side was made a little heavier, and the girders abutted against it and there had been no inconvenience of any kind. The Paper also stated that in Austria the Government had established 1 in Mr. Carruthers.

Mr. Carruthers. 22½ as the maximum gradient for the rack. Of course it must be very pleasant to Austrian engineers to have a "superior person" to instruct them what gradient they were to use, but it did not appear to him that that particular gradient was the one that ought to be chosen; in fact, 1 in 22½ appeared to be coming very nearly to the limit where the adhesion incline was available, whereas the rack was working with perfect safety at an incline of 1 in 1. In reality, however, he considered that the speed of the trains fixed the limit at which adhesion was insufficient, the gradient being only indirectly influential. There was, however, a lower limit to the speed below which it was not desirable to go, and, in most cases, a locomotive would have sufficient adhesion, without the rack, to draw any load, which it could take at that speed, up a gradient flatter than 1 in 20. Mr. Pownall might be congratulated that he had no one to instruct him, and was allowed to use his own judgment as to what gradient he thought best, the result being that he was able to give the Japanese Government a far better line than if he had been kept to 1 in 40 as the maximum gradient.

Mr. Shervinton. Mr. T. R. SHERVINTON stated that when the Usui line was first proposed he had visited the Hartz Mountains, examining very carefully the line there. At that time it was intended to construct the long line, 15 miles round, but eventually the Abt system was adopted. Mr. Carruthers' remarks entirely coincided with his own opinions with regard to the 10 miles of extra line required for the purpose of securing a continuous gradient of 1 in 40. It was, of course, not only the question of making that line of 15 miles, but also the maintenance for years of 10 additional miles of line, and that was a strong reason for recommending the adoption of the rack system. The locomotives for the line were designed by Messrs. R. Abt & Co., who knew more perhaps about the system than anyone else, and it was considered that the engines would take up 100 tons. Climate had of course a great deal to do with adhesion matters, and it was not very favourable, as there was sometimes much wet, especially in the mountains. Then came the question of weight. The gauge was 3 feet 6 inches, and the rails 61 lbs. per yard. It was not considered advisable to make the engine very heavy, and the weight was therefore kept down as much as possible. Engines of a heavier type and of much larger power were now being constructed, having 1,270 square feet instead of 807 square feet of heating-surface. The grate-area and the weight were also increased. The engines would weigh nearly

53 tons—an immense weight for such a narrow gauge and such a light rail, but he had been assured that the weight would not be objectionable. The wheel-base was increased from 12 feet to 18½. Another great point was that it was being tried if possible to get rid of the products of combustion, which were found sometimes to be almost asphyxiating when there was a following wind. In order to do that a condensing arrangement very much the same as on the Metropolitan Railway was being adopted. The chimney was carried over the footplate, so that the following wind, which had previously almost kept the steam and smoke right upon the footplate was now thrown behind the driver, and it was hoped by that means to do away with some of the trouble. Mr. Shervinton.

Sir DOUGLAS FOX thought those who had had the privilege of personally examining some of the mountain railways of Switzerland would realise that in them there was a wonderful adaptation of means to an end, and that the Swiss engineers had shown great boldness in the work they had undertaken. They had probably had a larger experience than the engineers of any other country in that particular class of work. English engineers, however, had had the honour of attaining the greatest height known for any railway, viz., that of the Oroya Railway of Peru, which started from the sea-level and attained a height of 15,720 feet. Great Britain offered not a few opportunities for works of this class, which would prove of great benefit to the population, but, until quite lately, it had been found impossible to obtain the necessary powers in the face of opposition from landowners. A more enlightened public spirit had, however, at length prevailed, and a railway up Snowdon, rising some 3,000 feet in a little under 5 miles, was now under construction. In preparing for this work he had had the advantage of examining in some detail many of the Swiss railways, and would like to mention some of the salient points to be observed in dealing with works of that special character. They might be divided into three classes. First, railways wholly worked by rope—funicular railways, as they were called—which had been largely adopted for comparatively short lengths. But, as would be at once realised, a rope, though at first sight it might appear an element of safety, was, especially when the length was great, very often quite the contrary, leading, when brakes were improperly applied, to dangerous shocks, and, if fracture took place, to serious damage to the train. As would be seen from the Tables in the Papers, such railways were either Sir Douglas Fox.

Sir Douglas Fox. very short, or were divided into short lengths. Certainly one of the most notable examples of a rope-railway was the Stanzerhorn, which was divided into three sections, each worked by a separate rope. Secondly, there were railways wholly worked by the rack, with gradients varying between 1 in 12 and 1 in 1·6. Those which exhibited perhaps the most beautiful adaptation of all were partly worked by rack and partly by adhesion. Those who had seen either the Brünig or the Zermatt railways in Switzerland would agree that, not only in their general adaptation, but in their details, they were very beautiful structures; and they had certainly been so laid out as not only to do no damage to the country through which they ran, but to enable passengers to see the beauty of the scenery in a remarkable way. It had been generally found, that a narrow gauge was convenient for such mountain railways, because in almost every case very sharp curves were necessary. In Switzerland the standard width adopted was about 2 feet 8 inches, which allowed of carriages 6 feet wide, with four passengers abreast. Curves had been used of under 2 chains radius; but the experience of the Swiss engineers was against such sharp curves, even on that narrow gauge, and they strongly advised that they should not be less than 4 chains. With a 4-chain radius, and with gradients properly compensated, the trains ran smoothly, safely, and well. It was a very important matter, in dealing with such very sharp curves and with sudden changes of gradient, that the rails should be most carefully bent to the curve, and also to the gradient. With reference to the gradients, the cost of the working appeared to mount up very high after getting to anything steeper than 1 in 4, which, it seemed desirable should be, as far as possible, the maximum. There were several points that had been referred to in the Papers, having a special bearing upon mountain railway construction, on which he should like to touch very briefly. The first had reference to the treatment of snow, and, what was probably even more to the point in this country, falling stones. Attempts had been made, at great expense, and sometimes successfully, to block avalanches or falling stones; but he thought that the study of those forces of nature would prove, that the proper course to deal with them was rather to humour them than to attempt to stop them; in other words, to try and turn them aside from the work, instead of allowing them an opportunity of exerting their full force against it. A most important matter in all those railways evidently was to provide thoroughly for torrential rain, and for melting snow. That was done by placing heavy pitching on the side gullies, on the upper side of the banks, and in cuttings, by

which means the earthwork and ballast were protected from being washed away. Ample waterway for the passage of floods was also necessary. Reference was made to its not being advisable to use iron girders with steep gradients, and he thought there could be no doubt that masonry was better. Iron girders were, however, very largely used on mountain railways, and they were very cleverly anchored by means of a special bearing plate, which was actually attached to the girder and was let into the bed-stone at one end, the other being left free for expansion, the lower abutment of each bridge being made considerably stronger than the upper one. Of course, one of the most important matters was to deal with the tendency to slide caused by the tractive force on the rack. That was met by a number of vertical iron stops, which were either let into the solid rock or into blocks of concrete, so placed as to touch the edge of one of the sleepers, about one in every 50 yards of steep gradients, and one in 80 or 100 yards of flatter gradients. Fish-plates were also fitted with six bolts instead of four, and, in the better railways, those of later construction, there was generally an intermediate fish-plate in the middle of each 30-foot rail. In order to prevent the sleepers from being damaged by the thrust against them of the downward force, they were filled with wooden cores at the point where an angle-bar fitted to the rack bore against them, so that there was no tendency to bend the sleeper. A very important question which had arisen in connection with those railways had reference to the relative advantages of the two forms of rack which now appeared to have the field between them and were very strong competitors, viz., the Riggenbach (the older one) and the Abt. The Riggenbach, as far as he had been able to ascertain, worked well, and was durable if it were carefully fitted, but if it once shook loose, it was impossible to put it right again without taking the whole of that length of rack out, and even then it was difficult to make a good job of it. There was, under certain conditions, a tendency in the locomotive to mount this class of rack, and travelling on it was certainly not anything like so smooth. Anyone who travelled on the two systems would be able to detect at once when he passed from the Riggenbach (which was something like the steps of a ladder), where there must be a certain amount of clearance, on to the Abt. The rack ladder system, however, had been at work in rather a crude form on the Rigi for some twenty-five years, and it was wonderful to consider that the railway had worked so many years without any serious hitch or difficulty, although the loco- Sir Douglas Fox.

Sir Douglas Fox.

motives were by no means provided with the same safeguards as the later ones on other railways. The Abt system had the great advantage of duplication or triplication. Two racks (in some cases three) were placed side by side, enabling the locomotive to take hold independently, and by that means all shocks were avoided. The travelling was exceedingly smooth, and the wear and tear was reduced to a minimum. His own opinion, after careful investigation, was, that better and safer results might be expected with a less cost of maintenance from the use of the Abt system, than from the adoption of the Riggenbach. On some of the mountain railways in Switzerland, and certainly on the American railways, wooden sleepers had been adopted, but that he thought was a mistake. It was, he believed, a case of false economy, because there, if ever, was a case in which it was necessary to have the whole of the permanent way bound together as a rigid frame, and to introduce a material like wood, in connection with steel rails and steel rack, was, in his opinion, an error. Although the steel sleepers were in many places more costly, it would be economy in the long run to use them throughout mountain railways of steep gradients, and they should not weigh less than 56 lbs. each for a gauge of 2 feet 8 inches. He also thought it was a mistake, made on some lines, to have the rails too light. Some of them had been only 20 or 25 lbs. to the yard, and he thought the experience of Swiss engineers was, that they should not be, in any case, of less weight than that of the metre gauge State railways of India—41½ lbs. With reference to the locomotives, a great improvement had been made of late years. Perhaps the most important was the introduction of duplicate rack-wheels, very neatly connected together by a spring arrangement, so that they were always working in harmony. That introduced a very great advantage in the important direction of perfect safety to the train. The brakes had been found very efficient. The best locomotives had two hand-brakes, duplicated, in order that, if one failed, another should be available. They had also a steam brake. A vacuum brake was first introduced, but as far as he had been able to ascertain, it was gradually being superseded, for mountain purposes only, by a pressure-brake. In addition to that, in the case of later railways, there was a very ingenious automatic brake, which not only came into play in case of any accident, but also prevented what he believed had been the only cause of serious accident—allowing the train to run beyond the proper speed. During the whole period of working of Swiss mountain railways he believed only one serious accident had occurred, and that was

Sir Douglas Fox.

on account of the engine-driver, not being quite his own master, allowing the train to run at about twice its normal speed, so that it jumped the track and ran off the road. That was rendered impossible by the automatic brake, which worked by means of a governor, and entirely prevented the train being run beyond the speed fixed by the company. The cars generally held between fifty and fifty-six passengers each. In this country a question would, he thought, arise as to how far the Board of Trade would sanction some of the arrangements for working the traffic. There were cases in which two cars were used, pushed in front of the locomotives up the steep inclines. He thought it was quite clear, if there were only one car, that would be the proper course, but how far it would be safe to push two cars in front of the locomotive, he thought was doubtful. A plan which had been proposed, and which perhaps had some advantage, was to place the locomotive in the middle so as to push one car and pull the other, because it was found on very steep inclines, that it was not a safe thing to trust to draw-bars for a heavy train behind the engine. He had ventured to make those observations bearing upon the details of Swiss Railways, because he thought it was important that, as English engineers, they should study everything brought before them, although their sphere for such employment in this country was comparatively limited. He thought the railways in question had brought about a wonderful change in Switzerland, and all who were, like himself, fond of mountains for recreation purposes, must be glad to know that so large a number of people had been able to enjoy the great advantages of those high regions through the skill of their brethren, the Swiss engineers.

Mr. Burnett.

Mr. R. H. Burnett found that the Papers, taken as a whole, covered such a large range of questions of great interest connected with the working of railways, that it was not easy to select points on which to offer remarks within the brief time available for discussion. In the circumstances, he purposed directing his remarks first to the general question of the efficiency of locomotives when employed in the working of steep inclines, and then to give some examples from actual practice of adhesion-locomotives, as a supplement to the interesting Table attached to Mr. Collett's Paper, giving the leading dimensions and the loads drawn by engines on various inclines throughout the world, of gradients ranging between 1 in 45 and 1 in 4. With regard to the efficiency of the locomotive, it was, perhaps, hardly realized how greatly this was affected by the speed at which it ran. The locomotive, when running at high speed, was one of the most economical

Mr. Burnett. of high-pressure engines, using only, say, 20 or 25 lbs. of water per I.HP. per hour; but when at low speed it consumed between 30 and 35 lbs. of water per I.HP. per hour, and its performance per ton of weight and per square foot of grate was comparatively a poor one. It was highly important, therefore, when comparing the efficiencies of locomotives of different types working steep inclines, to take into account the speed at which the trains were run. It was noteworthy, therefore, that this element was omitted altogether from consideration in Mr. Collett's as well as in Mr. Berg's Paper. In Mr. Pownall's Paper it was referred to, and he made use of the very practical measure of "ton-miles" per hour in comparing the performances of certain engines; but the influence of speed on the efficiency of the locomotive, as measured either by HP. per hour or by ton-miles of load hauled per hour, did not seem to have been taken into account. He proposed to exemplify the influence of speed on the duty of which a locomotive was capable by reference to the performance of some engines on the New South Wales railways, of the adhesion type, working the steep inclines of that colony, fifty of which were made some three years ago by the firm with which he was now associated (Messrs. Beyer, Peacock & Co.) to the general dimensions and specifications of Mr. Thow, Chief Mechanical Engineer to the New South Wales Government. The specification required these engines to be capable of taking 170 tons (exclusive of their own weight) up continuous inclines of 1 in 40 at a speed of 20 miles an hour, while the weight per axle was limited to 14 tons. They had also to be capable of running at a speed of 45 to 50 miles an hour on the flatter portions of the line, after surmounting the steep inclines. The problem was therefore not an easy one; because, while the duty specified necessitated a very large boiler and firebox, and, therefore, a heavy engine, the limit of weight per axle was low. This occasioned the use of five axles, and, to enable the necessary adhesion to be obtained to meet the tractive effort which the engines had to exert on the 1 in 30 and 1 in 40 inclines, three of the axles had to be coupled, the size of the wheels being limited to 5 feet diameter, not only to keep down weight, but to obtain the requisite tractive power with cylinders not exceeding 20 inches diameter by 26 inches stroke. Having prefaced thus far, he came now to the performance of these engines, in exemplification of what he had said about the element of speed materially affecting the efficiency of the locomotive. In the report of the New South Wales Railway Commissioners for June, 1894, various typical engines were illustrated, and the loads they took at different

speeds on the various gradients of the New South Wales railways were stated. The following Table, derived from the Report, gave Mr. Burnett.

NEW SOUTH WALES RAILWAYS.

Performance of Ten-wheeled Express Passenger (6-coupled) Engines at various Speeds on various Gradients.

Horse-power.

Speed, miles per hour	35	30	25	20	15	12	10	
Gradient	1 in 100	1 in 75	1 in 60	1 in 40	1 in 100	1 in 75	1 in 60	1 in 40
Load drawn, tons (exclusive of engine and tender) . .	255	260	270	225	600	505	415	275
HP. developed, total (including engine and tender) . .	1,250	1,240	1,230	1,100	930	790	660	660
Do. per square foot of grate	45·4	45	44·7	40·4	33·8	29	24	
Do. per ton of engine and tender . .	14·2	14·1	14	12·6	10·5	9	7·5	

Ton-Miles.

Speed, miles per hour	35	15	30	12	25	10	20	10
Gradient	1 in 100		1 in 75		1 in 60		1 in 40	
Load drawn, tons (exclusive of engine and tender) . .	255	600	260	505	270	415	225	275
Ton-miles per hour (exclusive of engine and tender) .	8,925	9,000	7,800	6,060	6,750	4,115	4,500	2,750
Do. per ton weight of engine and tender	100	102	88	68	76	46	51	31
Decrease in efficiency, per cent.	..			23		40		40

the loads and speeds for the engines he had described, as determined by actual practice, and he had compiled also a column of particulars of the engines and loads in the manner given in the Table appended to Mr. Collett's Paper.[1] In that Table the HP. was worked out for these loads and speeds. He did not propose to detain the meeting by going into the whole of those particulars now, but he would briefly give the results, as bearing on what he had said about the influence of speed on the efficiency of the locomotive. The speeds varied between 10 and 35 miles an hour.

[1] See Appendix to Mr. Collett's Paper, p. 35, col. 2.

Mr. Burnett. The loads varied between 225 tons (exclusive of the engine and tender) and 600 tons, and the inclines on which the loads were drawn varied between 1 in 40 and 1 in 100, so that they had those locomotives working under every variety of conditions. The outcome of it all was that while, for example, these engines, when working the maximum loads of which they were capable, on an incline of 1 in 60, at 25 miles an hour, gave a duty equivalent to 44·7 HP. per square foot of grate and 14 HP. per ton of their weight, they gave only 24 HP. per square foot of grate and 7½ HP. per ton of their weight at 10 miles per hour with the maximum loads of which they were capable on inclines of 1 in 60 and 1 in 40. Those figures showed how quickly the efficiency of a locomotive decreased with a fall in the speed. At lower speeds the case would be found to be even worse. The moral of this was that speed was an exceedingly important factor in comparing the working of steep inclines by different types of engines, and any data on the subject from which that element was wanting were of comparatively little value when they came to be applied to the construction of a locomotive to perform a certain duty, or when the relative merits of adhesion and rack-railways came to be discussed. In that respect the Table in Mr. Collett's Paper—however interesting and valuable in other respects—was deficient, the element of speed being absent. It might be noted, too, that it did not give the grate-areas of the various engines, although the grate-area of a locomotive was one of its fundamental features. In the absence of particulars of speed it was impossible to draw any useful comparison or conclusions from the ratio of the train-loads to the weight of the engines given in that Table. He observed that the ratio of 3·56 [1] was given as the performance of some engines on the 1 in 28 inclines of the Darjeeling railway, which was a very high performance for that gradient. It would, therefore, be interesting to know at what speed that load was hauled.

It might not be out of place to supplement the particulars he had given regarding the performance of the New South Wales passenger engines by particulars of the performance on the 1 in 30 inclines of that colony of some goods engines that were made in 1881 by Messrs. Beyer, Peacock and Co. to his specification, when he had charge of the locomotive department of New South Wales. These engines were of the type known as the "Mogul"—that was,

[1] This figure has been subsequently corrected to 2·5, in col. 6, p. 36.—Sec. Inst. C.E.

they had six-coupled wheels and a two-wheeled bogie in front, with outside cylinders. They had been designed to take heavy loads up the 1 in 30 and 1 in 33 inclines, laid with 8-chain reverse curves, over the Blue mountains, which rose 3,300 feet in 30 miles. They possessed all the special features claimed for the American engine by its advocates, in having abundant vertical and lateral flexibility, balance beams being provided to all the coupled axles, in conjunction with a short rigid wheel-base, not exceeding 11 feet, while they had all the good characteristics of the English locomotive in respect of simplicity of design and substantiality and finish of detail. And yet, while they were powerful and substantial, they were amongst the lightest engines for their power that were ever constructed. Twenty of these engines had been ordered in the first instance, and they had proved so successful that fifty more had been added by his successors to the same drawings, while more recently a considerable number had been added to the stock by other makers, only very slightly altered from his design, the main alteration being a slight increase in the ratio of heating-surface to grate-area. Mr. Burnett.

After he had ceased his connection with the railway, the engines were challenged to a trial by the advocates of American engines in competition with one made in the United States of the same type, but with somewhat larger driving-wheels, a few of which had about that time been introduced into the Colony. The result of the challenge was that a set trial under Government auspices was made, which brought out the capacities of the two engines in question, and the American engine was badly beaten. The English engine hauled 194 tons (over and above the weight of the engine and tender) up inclines of 1 in 30 and 1 in 33 for a distance of 5 miles at the rate of 9½ miles an hour. That performance gave a load of 3 to 1 on an incline of 1 in 30 at 9 miles an hour, which was a performance that had never, he thought, been beaten, if equalled, by any tender engine at home or abroad. The HP. performance was equal to a total of 520, giving 25 HP. per square foot of grate and 8 HP. per ton of weight at a speed of 9 miles an hour. On the same trial the engine took 161 tons over the same length at 12 miles an hour, which gave a total HP. of 590, equal to 28 HP. per square foot of grate and 9·2 HP. per ton of weight at 12 miles per hour; and those engines were capable, as an every-day duty, of taking 150 tons up the 1 in 30 inclines at a speed of 10 to 12 miles an hour. Having given some information from actual practice as to the performance of adhesion locomotives on steep inclines, he would

Mr. Burnett. remark that the point he had desired to emphasize, in calling attention to the relatively poor performance of adhesion locomotives at the lower speeds, was the tendency there was to overload engines in working very steep inclines. The traffic department clamoured for an extra wagon to be put on, and if only the engine was capable of moving the load, however slowly, the locomotive department was, as a rule, coerced into assenting to it, and there was a liability in that way to tack on to the engine more than the proper load, and as a result the speed was unduly restricted and the performance of adhesion-engines accordingly made to compare unfavourably with other means of traction.

As an example in point of the advantage of keeping down the load somewhat below the full maximum tractive effort of which an engine is capable, in order to obtain a higher rate of speed and a consequent higher efficiency, he would refer, for a moment, to the La Guaira and Caracas engines made in 1888 by Messrs. Beyer, Peacock & Co., to the specification of Messrs. J. Livesey & Son, which engines were incidentally mentioned in the Appendix to Mr. Collett's Paper.[1] It was there stated that those powerful adhesion-engines hauled, for the first six months, 68 tons up the 1 in 27 incline (23 miles long), but now hauled only 51½ tons, the change having been made in order to increase the speed, so as to cover the distance of 23 miles in one hour fifty minutes. That gave an average speed of 15 miles an hour; and if the load were multiplied into the speed it gave 772 ton-miles an hour. Unfortunately, the speed at which the 68 tons were hauled was not given, but probably it did not exceed 9 miles an hour; and 68 multiplied by 9 gave only 612 ton-miles an hour, as against 772 ton-miles with the slightly less load and much higher speed. That, however, was only an assumed result in the absence of the actual rate of speed at which the 68-ton load was hauled; and its absence in that case only emphasized what he had said as to the incompleteness of data about locomotive haulage when the rate of travel was omitted. There was one other point to which he might allude in this connection, as the result of his experience of working traffic over the steep inclines of the New South Wales railways, and it was the importance of relatively large cylinder-capacity in engines intended for working steep inclines at low speeds—that capacity being obtained by a long stroke, to obtain the greatest piston speed possible, or, failing that, by large diameters. It was not

[1] *Ante*, pp. 32 and 36.

Mr. Burnett.

exceptional for those who were accustomed to the proportions of cylinder-capacity to grate-area usual in locomotives for fast running on comparatively level lines, to criticise the engines used, for example, on the New South Wales railways as being "over-cylindered." But this so-called over-cylindering enabled the steam to be cut off earlier in the stroke than would otherwise be possible, resulting in a higher rate of expansion and a consequent economy of steam, which enabled the engines to "hold their water" at higher speeds than would otherwise be the case. This feature was an important factor in the successful performance of the two classes of engines working on the steep inclines of the New South Wales railways of which he had given particulars, the passenger engines having cylinders which gave a tractive power equal to 173 square inches of piston-area, and the goods engines having cylinders which give a tractive power equal to 176 square inches.

He now came to rack-haulage, and he would refer in the first instance to the rack-engines of the Puerto Cabello and Valencia Railway, constructed in 1887 by Messrs. Beyer, Peacock & Co., under the Livesey-Lange patent. They were purely rack-engines. The type had been adopted because the incline on which they were to work was limited to one portion of the railway, with inclines of moderate steepness at either end, on which pure adhesion engines could work the loads. Moreover, at certain seasons of the year that portion of the line was so overrun with locusts as to interfere materially with the adhesion by the crushing of their bodies on the rails; and in view of that and of the simplicity of construction that would result from making the engines purely rack, it was decided to give up adhesion altogether in their case. The features of those engines were that the rack-pinions and shafts (of which there were two) were carried in frames attached to the axle-boxes of the carrying-wheels instead of those frames being carried by separate bearings on the carrying-axles, as in the Abt system. By that mode of carrying the rack-pinion frames, not only was the number of the bearing-surfaces and axle-boxes reduced, but the strains thrown on the shafts and bearings were much lessened by being opposed to each other in the same planes instead of in different planes. A second feature of those engines was that each rack-pinion was driven by its own pair of cylinders, so that coupling-rods were avoided, and what was even more important, it was rendered certain that equal work should be done by both pinions. He should point out, however, that while there were four cylinders, there was no unusual complication of valve-motion, as both cylinders on

Mr. Burnett. either side of the engine were served by one steam-chest and link-motion. He referred to that, as he observed in the note in the Appendix to Mr. Collett's Paper that these engines were stated to have four "independent" cylinders.[1]

He would next refer to the engines made more recently by Messrs. Beyer, Peacock & Co., to the specification of Messrs. J. Livesey & Son, for working the steep inclines of 1 in 12 of the Transandine Railway, of the metre-gauge, connecting Mendoza with Chili. They were combined rack- and adhesion-engines—the rack gearing being constructed under the Lange-Livesey patent, as in the Trincheras engines. The combination of rack and adhesion in the engines was adopted because the lengths on which the rack rail was laid were intermittent, occurring at three or four places in the midst of lengths of 1 in 40, on which the engine worked by adhesion alone. Moreover, the rack inclines were comparatively short—about 3 miles in the aggregate—while the 1 in 40 inclines amounted in the total to about 22 miles. The rack working might be regarded therefore as only supplementary to the adhesion working. The engines were provided with two pairs of adhesion driving-wheels, coupled together, and driven by one pair of cylinders, and a single rack-pinion driven by another pair of cylinders—all the cylinders being outside—which together gave a tractive power equal to 220 square inches of piston-area. They had 20 square feet of grate, so that for a metre gauge they were exceedingly powerful engines, and were remarkably well adapted for going round sharp curves, as the rigid base was but a little over 10 feet, although steadiness in running was ensured by their total wheel-base being 19 feet. They were fitted with steam-sanding apparatus to the adhesion-wheels, back and front, and carried upwards of 1,000 gallons of water. They started running in the end of 1893, going to work without the slightest hitch, and up to the date of the last advice were giving the greatest satisfaction; but in consequence of the line not having then been opened for regular traffic, the work on which they were engaged was not of a nature to test their capabilities to the full.

Reference had already been made by Mr. Shervinton to the new engines that Messrs. Beyer, Peacock & Co. were constructing for the Usui Railway, to his specification, and little remained for him (Mr. Burnett) to say in reference to them. The engines had a tractive power equal to 260 square inches of piston-area, with 20 square feet of grate, and the main difficulty in designing these engines was to

---

[1] *Ante*, p. 33.

embody that power and size of engine on so narrow a gauge, and within the very limited over-all width specified of 8 feet 8 inches. As the result of his experience of the working of the Metropolitan Railway, he felt confident that the condensing apparatus with which they were being fitted would be found to greatly diminish the discomfort which the men now experienced from being enveloped in the steam and products of combustion in the tunnels in certain directions of the wind, besides conducing to economy of working by heating the feed-water. Mr. Burnett.

Mr. E. E. SAWYER observed that it was very curious to note in the Table accompanying Mr. Collett's Paper, that not one of the railways could be found in Great Britain, but they had been taken from all parts of the world. Four or five adhesion-inclines were mentioned, and as there were adhesion-inclines working in England, even on some of the main lines, it would have been interesting to have the details of their manner of working. He supposed it was done by adding one or more engines; but even the details of that would be useful. With regard to the rack, or other special appliances, he believed there was not a single instance of the kind in Great Britain. One could hardly believe, however, that there was no occasion for the use of such railways, and English engineers must therefore be rather behind-hand in the matter, or were prejudiced against such systems and more especially against the introduction of special sections in an ordinary line of railway. The matter had been referred to by Mr. Pownall, who had given a very good instance, taken from the Canadian Pacific Railway, in which he considered that a special section of line might be laid down with very advantageous results. Exception had been taken to the proposal by Mr. Carruthers, who thought that it was not possible. In fact, he had stated that whatever might be the style of machinery employed, if there was a certain HP. to be used the same amount of work would be derived from it, and he added, "let two pairs of rails be considered, one with a rack, and one without a rack, working those two pairs of rails with engines developing the same HP. If it could be believed that one pair of rails would do twice the work of the other, he thought it went very nearly on the road to a belief in perpetual motion." Of course, a test of that sort would be exactly what was required, and he thought he could lay before the Institution an instance of the kind referred to by Mr. Pownall. The railway between Delagoa Bay and Johannesburg, 380 miles long, was one of the main lines in South Africa, connecting Cape Town with Delagoa Bay *viâ* Pretoria and Johannesburg. About half way between Delagoa Bay Mr. Sawyer.

Mr. Sawyer. and Pretoria there was an incline, which happened to be nearly the same length as that on the Canadian Pacific Railway, viz., $2\frac{1}{2}$ miles, and almost the same gradient—1 in 20, as against 1 in 22. The line rose from Delagoa Bay very gradually, with gradients of 1 in 50, to about 5,000 feet, when it came to a narrow gorge, or rather a face, in which there was no room to turn, and where the line had to rise suddenly 1,000 feet more to get on to the plateau, 6,000 feet high. The line was laid out by Dutch engineers, and as far as he could see, was very well laid out indeed. If the 1 in 50 gradient had been continued it would have involved an enormous outlay, and there would have been a tunnel nearly 2 miles in length. It was accordingly decided to have a special arrangement, and adopt the rack, on (he believed) the Riggenbach system, or one analogous to it. Locomotives of 46 tons were used, six wheels coupled, with cylinders of 430 millimetres or $16\frac{7}{8}$ inches diameter, and 24 inches stroke. The rack locomotive had four wheels coupled, weighing only 32 tons, with cylinders $18\frac{7}{8}$ inches diameter, and 24 inches stroke, giving approximately one-fourth more HP. than the adhesion locomotive. Trials were taken of both; they went over the incline at a rate of about 4 miles an hour, and it was found that under the most favourable circumstances the adhesion locomotive took up five loaded trucks, or 80 tons, but in practice for ordinary conditions the load had to be reduced to four trucks, or 64 tons. The rack, on the other hand, took eight loaded trucks, or 128 tons, double the amount, thus confirming Mr. Pownall's statement that if the rack was substituted on the section of the Canadian Pacific it would double the result. Such a fact ought not to be astonishing, because, after all, in adhesion, the slip was practically the limit of efficiency. In the case of the rack, the Fell, or the rope, the limit of efficiency was the strength of the materials. Increase the HP., and, so long as the materials held out, the HP. would be converted either into greater speed or into greater load. They could therefore quite believe in a rack line doing twice the work of a similar adhesion line, without getting nearer a belief in perpetual motion. With regard to the working, of course a traffic manager objected strongly to the interposition of a specially worked system in a line. On the Delagoa Bay line this created no inconvenience. The trains came up to the foot of the incline with the adhesion locomotive in front, the rack locomotive simply went behind like an ordinary bank engine, and the whole train went to the top of the plateau without in any way being interfered with. If it were done by adhesion merely, it would require at least three locomotives, if not

four, to take up the same trains. Mr. Pownall had also remarked that "when a gradient of about 1 in 40 cannot be obtained for an adhesion line, the value of combined rack and adhesion begins to be perceptible." That was quite right. He thought there was no engineer who would think of introducing any special system for a gradient of 1 in 40. He thought there was a limit also to the advantage of the rack as compared with the rope. The Brazilians, curiously enough, were among the earliest to adopt the rack. At Rio there were two examples of the rack; one was the line up the Corcovado, a small passenger line to take people to the top of the mountain to see the view. The rack was worked up to a gradient of 1 in 2. The other line, the Petropolis Railway, was intended to be a main trunk-line; but, of course, the intentions of the Brazilian Government were not always carried out, and the line had not been extended. It had 5 miles of rack incline, with gradients of 1 in 6. To show how difficult it would be to work it as a main line, it might be mentioned that the train arrived at the foot of the incline with about twelve carriages. It was then broken up, and one locomotive was put to every two carriages, so that six rack locomotives were required to take up a train which had been brought by one adhesion locomotive. Any-one seeing the six locomotives puffing up the incline, and had also seen the working of an incline by a rope-railway, could easily realise the great advantage of the one over the other. The incline of the São Paulo Railway was 5 miles long, with a gradient of 1 in 9. It was not only on a trunk line, but it was the neck of the bottle for a system of over 1,000 miles, and it conveyed the traffic up and down perfectly. With regard to inclines generally, just as the rack, the Fell, or any system of that kind, was superior for gradients of 1 in 20 to adhesion, so the rope-railway was superior to the rack or the Fell for a gradient of 1 in 10. With reference to the danger of pushing of two cars mentioned by Sir Douglas Fox, there was an instance of that kind on the Petropolis Railway, and, as far as he had heard, there had never been any accident from that cause. The gradient in that case was 1 in 6. Mr. Sawyer.

Mr. E. Woods, Past-President, thought the Authors were entitled to great credit for having brought before the Institution so many valuable facts with regard to the different systems of mountain railways in use in different parts of the world. They had gone very minutely into the description of three railways in particular, and Mr. Collett had mentioned in his Paper a large number of mountain railways, with short references to them. Many instances, Mr. Woods.

Mr. Woods however, had not been given of mountain railways constructed on the west coast of South America, but in Peru and Chili a large number of such railways had been formed. The two most important were the Mollendo-Arequipa and the Callao-Oroya Railways. They had been constructed at great expense, and carried out at the cost of the Peruvian Government, who had been good enough to entrust to him the superintendence of the materials sent out from Europe with which they were made. The Oroya Railway attained a summit level of 15,680 feet above the sea, crossing over to the other side of the Andes. These railways, which had existed for many years, had been made by Messrs. Meiggs. Certain mountain railways had since been made in Chili, also of considerable importance, some of them connected with the great nitrate fields occupying the valley of the Loa, between the higher ridge and the lower range of the Andes. They ascended from ports on the coast and traversed a very rocky mountainous country, generally following the line of certain valleys up to the first ridge of the Lower Andes, thence descending slightly into the valley behind, where the nitrate grounds existed. Those grounds were, no doubt, well known to many of the members. The soil consisted of loose earth impregnated with nitrate, which was found in beds 3 or 4 feet thick, not much below the surface, and worked out from open pits. The material, which was called caliche, a mixture of earth and nitrate of soda, was either sent to the coast by the railways, or treated on the spot near to the termini and converted into pure nitrate of soda. In the one case the quantity of material sent down was naturally very much greater than in the other, where the nitrate of soda was manufactured on the spot. That was done by dissolving the earth in water, in boilers and pans, with a furnace underneath. The concentrated liquor, saturated with salt, was then run off and evaporated down to the point of saturation, when crystals are deposited. The salt was then removed from the tanks, placed in bags, and sent to the coast. It might be sufficient to give one or two typical cases. One was that of a line[1] commencing at the port of Tocopilla, about 700 miles north of Valparaiso, and terminating in the Loa Valley, practically on the site of the nitrate beds. The country through which the line passed was very rough and rocky. To a summit level, distant 18 miles from the port, the line rose on a gradient of 1 in 25. The mountains were so steep approaching the coast that it

[1] Minutes of Proceedings Inst. C.E., vol. cxv. p. 326.

had been necessary to make two reverses to attain that gradient. The line traversed the valley, and the curves were exceedingly numerous. They had to round the different spurs of the lateral valleys, and consequently the curves had in some instances a radius as low as 181 feet, varying from that to about 300 feet. There were, of course, curves of larger radii beyond, but those were the critical curves which the locomotives had to pass round. The whole length of the line was 55 miles, measured from the port to the terminus in the Loa Valley. The first ascent was continuous for 34 miles, of which 18 miles were on a gradient of 1 in 25, 9 on a gradient of 1 in 36, and 7 on 1 in 69. It reached a summit of 4,900 feet, and then had a comparatively easy descent into the valley of the Loa. The gauge of the railway was 3 feet 6 inches, and the rails 40 lbs. per yard. There was a good harbour, and vessels of moderate size could come alongside the pier at the terminus. As to haulage power, there were locomotives of the Fairlie type, and some made by Messrs. Kitson & Co., whose locomotives were on eight coupled wheels, with two four-wheel bogies, one at the back and one in front. The difficulty, of course, had been to get round the very sharp curves of 180 feet radius. Some trouble had occurred at first, but it had been overcome, and he believed there had been only one accident since the opening of the line. That was not owing to the engines, but arose from the fact that the brakesman had neglected to do what he was ordered—to put the brake on before descending the incline. The result had been that in going round one of the curves the engine and train were thrown over, down a precipice, and the brakesman killed. The adhesive weight upon the eight wheels was 33 tons. An automatic brake was applied to all the trains, and the greatest value was found to attach to that arrangement. Without it he was quite sure very serious accidents would have happened. It was so easy to control the motion and the speed that, if the brakesmen paid proper attention to their work, no accident need occur. In the case of very sharp curves, the rails were connected together by iron ties as well as by the wooden sleepers. That preserved the railway at these points in perfect gauge. It was found that the engines took about 90 tons gross load up a gradient of 1 in 25. There was one peculiarity with regard to the working of the railway—that the country was a very arid one, there being very little rain. There was consequently no water to be had over the whole course of the line, except at the Mr. Woods.

Mr. Woods. termini. At Tocopilla, the harbour terminus, the sea gave an ample supply, but not of a quality suitable for use in locomotives. At the Loa terminus there was plenty of water, but it was of a bad quality, being impregnated with salt, and could not be used in the locomotives. Distilling apparatus, a "multiple-effect evaporator" (so termed), had therefore been erected, by which from 16 to 20 lbs. of water could be separated by 1 lb. of coal. Provision had also to be made for pumping water up from the river to the summit. The water, having been distilled, was pumped up by two compound-condensing engines made by Messrs. Fawcett, Preston & Co., delivering into a 4-inch main. That might seem small, but it was amply sufficient for the purpose. The main was 22 miles long, and was made of solid steel rods rolled into tubes on the Mannesmann principle. The pumps would each deliver 60 gallons a minute through a head of 1,427 feet, which was the height of the summit above the pumping-station. There was a pressure against the plungers equal to a head of 2,256 feet, or 983 lbs. per square inch, the pipes themselves having been tested to 2,000 lbs. per square inch. In that way water was supplied to the tanks not only at the summit but at intermediate stations. The works had been carried out by native labour under the direction of Mr. William Stirling, Mr. Hunter acting as his assistant resident-engineer during the construction and subsequently becoming the resident engineer on Mr. Stirling's retirement.

The second case which he would mention was that of the Antofagasta Railway. That was on another portion of the coast, also communicating with a portion of the Loa Valley, at a much higher point than the Tocopilla line. The railway ascended the western slope of the lower range of the Andes, crossing the summit at 4,200 feet, and then crossed the chain of the Andes to Bolivia, at a level of just over 13,000 feet above the sea. That extension had been made long after the first section to the nitrate grounds had been completed. The line crossed the same river, and, as far as the nitrate grounds were concerned, the first section of line applied to the traffic of that part of the country. The first section was 70 miles in length, with gradients ranging from 1 in 35 to 1 in 81 on the upper portion. The sharpest curves varied between 220 and 250 feet radius. The gauge of the line, which was now about 600 miles in length, was only 2 feet 6 inches. There was one important work that had to be constructed, a viaduct across a gorge on the higher part of the river Loa. The gorge was 800 feet in width, and the roadway 336 feet above the river, only

34 feet less than the height of the cross of St. Paul's. There was great difficulty in getting to it, there being no roads. It was necessary therefore to carry the railway to the top of the hill on the western side of the valley, to take the materials to that point by rail, and then carry them either down into the valley or across, by means of a cable 800 feet in length. All the material was carried over in a truck running on the cable and lowered down to the site. The valley was nearly 10,000 feet above the sea-level. With regard to the haulage power, the original engines had been supplied by Messrs. Robert Stephenson & Co., and later on engines had been obtained from American manufactories. Mr. Woods had had an opportunity of seeing many of the Swiss lines, both those worked by rope and those worked by rack. He had also had an opportunity of carefully examining the Mont Revard Railway at Aix-les-Bains, having been employed to report upon it several times during its construction. He had also travelled upon it last year after it was completed. The line rose from Aix-les-Bains, commanding views of the Mont Blanc range and other mountains. The traffic was pleasure traffic, the place being a health resort for patients who took their baths at Aix-les-Bains. The railway was a single line, 1 metre gauge, the rails being 40 lbs. per yard, with steel sleepers. On the steepest gradients, up to 1 in 4·77, there was a double rack, but on the lighter gradients there was a single rack. Mr. Woods.

Mr. Francis Fox (of London) pointed out that one of the most important questions connected with mountain railways was the question of efficiency and economy of working; but there was a still more important question, that of safety. It had been his fortune or misfortune during the last summer to be on two of the mountain railways in Switzerland when something went wrong, and it had been satisfactory to find that on both occasions the automatic brakes immediately did their duty. In one case it was a rope railway, one car being near the bottom of the mountain and the other near the top. The additional weight of the rope with the lower car tended to accelerate the speed beyond the maximum allowed, the consequence being that the brakes flew on; but beyond startling the passengers nothing happened. On a previous occasion both cars had been immediately arrested by the automatic brakes. The rope broke away from the upper car, flew round the top pulley and came running down the mountain-side like a long snake, and was piled on to the lower car. The brakesman had been killed. That was a danger to which rope railways were exposed. In the Mr. Fox.

Mr. Fox. other, without a moment's notice, there was a tremendous shock, and the train came to an abrupt stop. To the credit of the passengers it should be said that they sat still and stood fire very well. The first thing done had been to disconnect the engine and to tell the driver and fireman to look out, and, as soon as they turned on steam, to be prepared for the engine going to the bottom of the mountain. They turned on the steam, and fortunately it was all right. The engine went about 100 yards downhill and then came back and was attached to the car. All the passengers got out with a certain amount of deliberation, and the car and engine then started down the mountain. As soon as it was moved away from that portion of the rack on which the stoppage took place, it was found that the pinion had mounted the teeth of the rack. It was on the Riggenbach system. Possibly the same thing might happen with the Abt rack, but he had had no experience of it. In this particular case he had experienced it, and it certainly was not altogether a pleasurable sensation. It opened up a question which locomotive-makers should bear in mind, viz., that when the pinions mounted the teeth of the rack and lifted both wheels from off the adhesion rails, strains were brought on the axle which were certainly not anticipated. The axle was bent, and if it had broken it was a question what would have become of the automatic gear. With regard to boldness of engineering, he thought any engineer venturing to carry out such a railway as the Pilatus line was well worthy of the name. He wished to corroborate what had been said with reference to the São Paulo Railway. He had seen that magnificent work, built by the late Sir James Brunlees and Mr. McKerrow. It was a splendid railway, of 5 feet 3 inches gauge, conveying 700,000 tons of traffic during the year, almost entirely without accident. When he was there, there had never been an accident; one, however, had occurred about twelve months afterwards, but since that time it had worked with perfect success. The question of smoke in Alpine tunnels was a serious one. When ascending a mountain with the throttle-valve full open and the fire giving off dense volumes of pungent smoke, from the use of bad coal, the condition of affairs in the tunnels was almost intolerable, especially when the wind was travelling with the train.

Dr. Pole. Dr. W. Pole, Honorary Secretary, said he had been much gratified by reading the Papers, partly because he believed he was the first person who had introduced the knowledge of Swiss Mountain Railways to English engineers. He had formerly travelled much in Switzerland and had been pleased with the engineering

he had observed there. The Rigi Railway in particular had much interested him, and he had taken the opportunity of writing a Paper on it in 1873.[1] A good deal had been said in one of the Papers about the St. Gothard Railway, which was undoubtedly one of the most remarkable engineering works of Europe. But there was one feature of it on which further information would be interesting, namely, the ventilation of the long tunnel. He had had the opportunity of enquiring into the ventilation of the Mont Cenis tunnel, and had brought the subject before this Institution.[2] He had gone over the line with the engineer, who explained the whole matter to him. There was a mechanical contrivance for forcing air under pressure through pipes along the tunnel, so that if a man working there felt inconvenience from bad air, he could open a cock and surround himself with a fresh atmosphere. And there was also an exhausting apparatus at one end of the tunnel for pumping the air out. But neither of these provisions did much good for the general ventilation, and, in reality, the tunnel ventilated itself, for one half of it was on a very steep incline, and the air, getting heated by the locomotives, produced a current, making a sort of chimney, which ventilated the whole. He remembered that, when he went through it with the engineer, although a train had just passed the other way with the engine puffing as hard as it could going up hill, on arriving at the top of the incline he found the tunnel so clear that he could distinctly see the opening at the far end. Now in the St. Gothard tunnel there was nothing of the kind, for it was practically level with only such an incline as was sufficient for drainage, and yet, although he had been often through the tunnel, he was not aware of any inconvenience. It would therefore be interesting to know how the ventilation was effected and whether any particular system was followed. Returning to the subject of the present Papers, he might say that his account of the Rigi Railway in 1873 excited a good deal of attention, very few people in this country having seen or heard of it. He believed he was also the first to call attention, in the Proceedings of this Institution,[3] to the combination of the rack with the ordinary adhesion road. This was first adopted by the same engineer, Riggenbach, at some mountain quarries near Berne. He went, at the engineer's suggestion, to see it, and it was working very well; he noticed particularly how easily the transfer Dr. Pole.

[1] Minutes of Proceedings Inst. C.E., vol. xxxvi. p. 103.
[2] *Ibid*, vol. liii. p. 164.
[3] *Ibid*, vol. lxiii. p. 92.

Dr. Pole. was made between the two kinds of propulsion. The largest and best application of this system was in the Brünig Railway, a description of which he published in the *Times* of the 15th of September, 1888, the novelty and utility of the system being commented on in a leading article. The third kind of mountain arrangement, the cable-railway, was also described by him in the Proceedings,[1] as applied at Montreux; the ingenious automatic brake for stopping the car in case of the fracture of the rope being successfully used there. With regard to the last of the three Papers now before the Institution, he might state that the Author, Mr. Pownall, was a pupil of his, whom he had sent out to Japan; Dr. Pole had discussed the Swiss mountain system with him when he came to Europe to get information, and was much pleased to read the account of the good work he had done in introducing so successfully these ingenious and novel contrivances in that distant land.

Mr. Holtham. Mr. E. G. HOLTHAM was much interested in the efficiency of different classes of locomotives, and he had endeavoured to find some basis of comparison between the different locomotives in regard to their efficiency. He knew nothing better for the purpose than to take the HP. developed by each engine in its actual work, especially upon inclines, and divide it by the weight of the locomotive, thus getting a figure which enabled one to compare the work actually done by locomotives per ton weight. That gave some rather curious results, some of which he had not expected. He had taken five of the locomotives referred to in Mr. Collett's Paper—the simple rack locomotive used on the Montserrat line, a simple rack locomotive on the Trincheras incline, a simple adhesion engine on the Cantagallo Railway, and two instances of a combination engine, one on the Hartz line, and one on the Usui incline. Computing the HP. developed by each, he had found that on the Montserrat line it was about 151, the engine weighing 17 tons, giving a factor of 8·88. On the Trincheras line, the figure was almost exactly the same. For the simple adhesion engine on the Cantagallo line it was but slightly inferior; but on the incline on the Hartz Railway, though there was the very largest HP. developed, the weight of the engine was so great that the figure became very small—no more than 7·04. On the Usui incline it was still less—no more than 5·51. The comparison between the weight hauled by the engines, and the weight of the engines themselves, showed up differently, but that did not

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 406.

Mr. Holtham.

take into account the speed at which the trains were drawn or the incline they worked upon. The HP., however, necessarily did so, and it was therefore a better criterion. He was not prepared to find that the engine on the compound rack and adhesion principle would come out at such a disadvantage. There might be reasons to account for it, which, for want of time, he would not enter into. But he wished to call attention to the Hartz engine, referred to by Mr. Edward Woods, Past-President, who six years ago, in the course of a discussion on Mr. Carruthers' Paper and the Paper by Mr. Maxwell, on the cost of working the Hartz Railway, had pointed out that the combined rack-and-adhesion engine was a very efficient engine indeed on a railway of a slightly undulating character with steep gradients scattered about, separated one from the other.[1] Therefore, when he saw that an engine of that description had been placed upon the Usui incline, he could not help thinking that there must be some other reason for doing so, because there was one incline only, and nothing like it anywhere else in the country. There were on that length two small portions of the line with easy gradients, but those might be looked upon as extensions of the other lines. For instance, $\frac{3}{4}$ mile of the line was nearly level, and might be considered simply an extension of the 92 miles of line extending from that point to the west coast of Japan; it was therefore not necessary to make any special provision for it. The same might be said with regard to 1 mile at the bottom of the incline, which was simply an extension of the branch line from Takasaki, where a junction was made with the largest net-work of railways in the whole of the Japanese system. The conditions, therefore, were entirely different from those of the Hartz line, or lines of that class. There were no scattered gradients, there was no undulation, and he did not know why an adhesion-engine should be taken over that incline. Seeing the great superiority of the simple rack-engine in point of HP. developed (he would not say anything about the simple adhesion-engine, because the efficiency depended upon the state of the weather), he should have thought that there was no necessity whatever to carry a combined engine over that incline. When the engines first put on, turned out, as Mr. Pownall had said, to be somewhat unsatisfactory in their duty, he thought if they had cast off all the weight incidental to the adhesion, the outside cylinders and motion, coupling-rods, &c., and reduced the wheels

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 154.

Mr. Holtham. simply to the function of carrying, they would have had a lighter engine which would have given a higher duty, and would have worked the incline with a greater efficiency per ton weight of locomotive than they probably would obtain from the heavier engines now ordered for the line. It was, he thought, a matter for grave consideration whether there was any necessity to put a combination engine upon a single steep incline of sufficient length to utilise a special engine.

Mr. Vernon-Harcourt. Mr. L. F. VERNON-HARCOURT observed that Mr. Berg had given some references to the St. Gothard Railway from the Minutes of Proceedings, but he had omitted to allude to what he believed was the only Paper really dealing with the railway itself (the others dealing chiefly with the long tunnel), viz., a Paper on "Alpine Engineering."[1] When Mr. Berg referred to the ruling gradient, he probably meant the average gradient, because the average gradient which Mr. Vernon-Harcourt had given in the longitudinal section of the St. Gothard Railway was 1 in 42·8. On the Swiss side, which was the steeper of the approaches, the ruling gradient, or the worst gradient on the line, was 1 in 37. Reference had been made by Mr. Berg to the Davos Railway as being the highest in Europe worked by adhesion only. He was glad that Sir Douglas Fox had mentioned the Oroya Railway, because there were several railways, both in North and in South America, that went to a good deal higher elevation. The Oroya Railway was, he believed, the highest in the world, but even the comparatively new Canadian Pacific Railway went to very nearly the same elevation as the Davos Railway, and the Southern Pacific attained a still higher elevation. The Northern Pacific rose to a height of 5,800 feet, the Central Pacific to 8,250 feet, the Denver and Rio Grande to 10,850 feet. There were also other railways in Peru and Chili and Mexico which attained very high elevations. But really the difficulties in attaining a high elevation depended largely on the level at which they commenced; and in that respect the Peruvian Railways exceeded the Swiss by commencing at the sea-level and going up, in the case of the Oroya Railway, to 15,645 feet, and the Mollendo Railway to 14,660 feet. Another important point, in regard to the practicability of a high elevation, was at what height the lines were liable to be blocked by snow, and this naturally depended upon the latitude and climate in which they were

[1] Minutes of Proceedings Inst. C.E., vol. xcv. pp. 237, 261 and 278, and Plate 7, Fig. 4.

situated. He believed that the St. Gothard line was occasionally blocked by snow, though it only reached an elevation of 2,638 feet on the Swiss side, which was the coldest, before it entered the tunnel. Dr. Pole had asked a question with regard to the ventilation of the tunnel on that line. In that case, as in the case of the Mont Cenis railway, the engineers trusted almost entirely to natural ventilation. Fortunately, one end of the tunnel was in a warmer climate than the other, and therefore as a general rule there was a draught through it. It appeared to him that a little classification was wanted with regard to such lines. Mountain railways were referred to, but the question was what was really a mountain railway? The St. Gothard had been referred to by Mr. Berg as a mountain railway and in one sense perhaps it was so; but it would probably be more convenient to regard a mountain railway as a railway where some other system of traction was adopted besides adhesion. In some cases adhesion alone was used, surmounting gradients on Peruvian and Mexican railways up to 1 in 25. There were, it was true, on the Cantagallo line, Baldwin locomotives ascending a gradient of 1 in 12, but that was not a very economical way of working the line. He would therefore suggest that although one might call railways like the St. Gothard, steep-gradient railways, it would be better to reserve the term mountain railways for railways which used a rack or central rail as well as mere adhesion. Reference had been made to the Transandine Railway. In that case the Abt rack was combined with simple adhesion for very steep gradients. The steepest gradient was 1 in 12. He was glad to find that the Authors appeared to approve of the conjunction of adhesion with the rack system, because it appeared to him, on going into the question three or four years ago with regard to the different systems applicable to mountain railways, that that was the system most likely to prove useful for extending railways to places where economical considerations precluded the adoption of long tunnels or very deep cuttings, and therefore it might be the means of extending railways to mountainous districts which could not otherwise be reached. He thought also that the system as applied to through lines was of much more importance, if not to engineers, at least to the general public, because the tourist lines and cable-railways (like the one he ascended at Marseilles directly after it was completed in 1892, to a height of 237 feet in a very short time at an angle of 60°), though they were very interesting, really did not touch the very important question of increasing the capability of locomotion from one part of the world to another and furthering

Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt. the development of trade and traffic. He therefore thought that those tourist lines, though very interesting, like the proposed railway to the top of Snowdon, stood on quite a different basis to lines which enabled them to extend railway accommodation to places which would be otherwise deemed inaccessible at any reasonable cost.

Mr. Head. Mr. JEREMIAH HEAD was glad to have the opportunity of directing attention to two or three examples of mountain railways in the United States. The first was the line running from the city of Chattanooga in Tennessee to Look-Out Mountain. The lip of the mountain was 2,100 feet above sea-level, and the total elevation of the railway 1,500 feet. It was an adhesion railway with a 4-foot-8½-inch gauge. The total rise of 1,500 feet was accomplished in about 10 miles. The railway, indeed, went right round the mountain one and a half times, the average gradient being 1 in 35. The railway had fallen into financial difficulty, and he believed was now standing. The second case to which Mr. Head called attention was a line from the same city of Chattanooga to exactly the same place on the top of Look-Out Mountain; but instead of being an adhesion railway, it was one similar to the Stanzerhorn—worked by a wire rope. The length of the line, instead of being 10 miles to achieve the same height, was only 4,500 feet, or about one-twelfth the length. On some parts the inclination was as much as 1 in 2·8. It was narrow gauge. The cars were very similar to those shown in Fig. 17, Plate 1, but the safety apparatus was different. It was so arranged that should the rope break, wedges were introduced under each of the four wheels, which immediately mounted up on them, and the car slid down until it came to rest, as though on shoe-brakes. It appeared, therefore, that there was sufficient adhesion to bring the car to rest on the gradient above mentioned. The winding apparatus was very similar to that shown in Fig. 16; but instead of winding up one cage and letting down the other, it was on the endless-rope system, the rope having a snatch-block with a counter-weight at the bottom end to keep it always taut. This had the advantage of giving a constant load on the engine throughout the journey. The engine was at the bottom end, and had two 12-inch cylinders and a 24-inch stroke. The journey was accomplished in about 3½ minutes, averaging about 15 miles an hour. This railway was still in operation, and therefore the line under a mile long with a steep ascent had beaten the circuitous one with a slow ascent. The third case was that of a mountain railway between Salt Lake City in Utah, and Park City, 32 miles off. This was an adhesion line, of 3-foot gauge. It

passed over the Wasatch Range, which was part of the Rocky Mountains. On this line there were 9 miles with a 1 in 25 incline, and 3 miles with a 6 per cent. or 1 in 16·66 incline. The line was worked by a Baldwin consolidation engine, with four pairs of wheels coupled, and in front what was called a pony-truck on one pair, with a radial connection. The tender was on two four-wheeled bogies. The load on the four pairs of drivers was 30 tons. The maximum load on the non-drivers, *i.e.*, the tender, the heaviest train taken up, and the load on the pony-truck in front were—tender 20 tons, train 58 tons, and pony-truck 4 tons; making a total of 82 tons. This gave the result that the drivers took up 2·7 times the weight upon them, or including the weight upon them, 3·7 times. It was a matter of interest to engineers to know how best to take a given load up a given incline. He feared it was a kind of heresy to say anything against the locomotive, which had been invented and brought to its present state of perfection by English engineers, and which they were rightly proud of, yet they must admit that running a locomotive on a line backwards and forwards was of itself a disadvantage, because it was a heavy thing and did not actually carry paying load. The locomotive itself had invariably a very much heavier weight on its driving-axles than the weight on any other axle of the train. It was the weight of the locomotive which necessitated the heavy and strong bridges, the heavy rails, and so on, on the line. If a locomotive had power, as he believed it always had, to skid its wheels, it was evident that the maximum tractive force was equal to the resistance of the rails to that skidding, and that was termed adhesion. The adhesion of a locomotive had been stated to be, under ordinary circumstances on the level, from one-fifth to one-third the weight on the drivers. In the Appendix to Mr. Collett's Paper [1] a Baldwin adhesion engine with three pairs coupled, weighing 40 tons, was said to draw a load of 40 tons; or, in other words, the weight taken up an incline of 1 in 12 was twice that of the engine, presuming (although it was not quite clearly stated) that the 40 tons load taken up included the tender and the weight on the pony-truck in front. Now if 40 tons on the drivers would take up itself and another 40 tons, it was pretty clear that it would only tax the adhesion just the same if it went alone up double the incline. It would therefore take its own weight alone up an incline of 1 in 6, and in that case the coefficient of adhesion utilized might be regarded as 1 in 6. They might conclude that the number of horizontal Mr. Head.

[1] *Ante*, p. 39, col. 22.

Mr. Head. feet expressed in an incline per 1 foot rise, divided by the multiple of weight on the drivers, which any locomotive would haul up that incline, was the coefficient of adhesion. It expressed also the maximum incline which the engine would go up without any load at all. Mr. Head had examined the cases scheduled in the Appendix, and found in case 6 the adhesion utilized was equal to $\frac{1}{6 \cdot 14}$. In the case of the Utah Railway just described, it was $\frac{1}{4 \cdot 5}$. Taking non-adhesion lines, the coefficients of adhesion were equal, in No. 9 to $\frac{1}{8}$, in No. 12 to $\frac{1}{4 \cdot 5}$, in No. 13 to $\frac{1}{4 \cdot 8}$, in No. 17 to $\frac{1}{5 \cdot 5}$, No. 18 to $\frac{1}{4 \cdot 7}$. In the rack railways it went from $\frac{1}{2 \cdot 2}$ to $\frac{1}{3 \cdot 9}$. It seemed that the maximum incline up which an engine with all wheels driven could go, without drawing any load at all, was about 1 in 4. If it was desired to haul more than the weight of the engine itself, they must either lessen the incline below 1 in 8, or else resort to a rack or rope. The rack enabled them to get hauling-power without corresponding weight on the engine. In case 22, an adhesion line, with three axles, there were 13 tons on each axle in order to pull the load up. That was to say, to take 40 tons up 1 in 12 required three axles with 13 tons on each. No. 24, an Abt rack railway, took 45 tons up a steeper incline—1 in 8—with only $9\frac{2}{3}$ tons on each axle, showing very clearly that the rack enabled the work to be done with less load on the axles and therefore less stress on the line. Of course it would be a very good thing if they could do without locomotives altogether. The ideal railway would be one in which motors were attached to all the wheels of the cars and there was no locomotive at all. That would be so because, as the load was put into the car it would increase the adhesion in the same proportion. Such a case was exemplified in trolley-cars where the load was actually put above wheels which were driven by electricity and therefore the adhesion increased exactly with the load. There was such an electric-railway between Chattanooga and Mission Ridge in which all the wheels of the trolley-car were driven and the car travelled with perfect ease and safety up an incline of 1 in 10. There seemed to be no reason why even that gradient should not be increased, and why, with sufficient power supplied to the wheels, cars of that kind should not be able to mount as much as 1 in 5; in fact, anything up to the limit of adhesion.

If that were so, in isolated mountain railways, where passengers were chiefly conveyed, the trolley-car system appeared likely to eclipse all others. It certainly was capable of going up and down an incline of 1 in 5; the only thing moved was the car itself with its load, and the line might be light, simple, and cheaply built, seeing that the heavy locomotive was dispensed with. Mr. Head.

Dr. JOHN HOPKINSON said that in mountainous districts coal was dear and water-power was abundant and cheap. Mountainous districts, as a rule, existed, in his opinion, very largely for the benefit of climbers—at all events, for the benefit of tourists. To such people a mountain railway at all was more or less an offence; but it was a very much greater offence when the train was propelled by a locomotive generating any quantity of smoke and steam. Tourists, too, as a rule, suffered in passing through mountainous districts, such as St. Gothard, from the closeness of the tunnels through which they had to go. Such tunnels were numerous and often long. In all those respects steam was at a great disadvantage. It was a nuisance, and it enhanced what was already a nuisance. Water-power, on the other hand, if it could be applied to the propulsion of the locomotives, would minimise the annoyance; the railways would be more pleasant to travel upon and more agreeable to people visiting such neighbourhoods. Water-power was not readily applicable directly to traction purposes. There were cases in which it could be applied with great facility and effect. For example, on the line of railway rising from Lauterbrunnen up to the level of Mürren, the descending car was loaded with water, which served to haul up the ascending car. In a case like that, water-power was applied in one of the most economical forms; but an arrangement of that kind was not of a very general application. It involved a tolerably straight line of track, and precluded anything like curves—at all events, severe gradients would be difficult to work. The incline, too, must conform to something like the theoretical law which was put forward in one of the Papers. Electricity, on the other hand, was exceedingly convenient for purposes of that kind. It could be provided by means of water, steam, or any other power. It could be taken from water-power at the base of the line to any form of machinery at its upper end; it could be distributed to any point of the line, and the only objection against it was the question of cost. With regard to that point, there was possibly one element which came into very serious consideration, viz., the interval of time between the trains running upon the line. If the trains were at a considerable interval apart, it was clear that it Dr. Hopkinson.

Dr. Hopkinson. would be necessary to provide a quantity of machinery which, during a greater part of the time, was at rest, or was, at all events, doing no useful work. But against those disadvantages there were many very marked advantages. In the first place there was the advantage to which Mr. Jeremiah Head had called attention—that, with electricity, every running axle could be made a propulsive axle, and, therefore, the weight of the cars could be kept down to what was really necessary for the load to be carried, and steeper gradients could be worked. The gradient had been stated at something like 1 in 5 by Mr. Jeremiah Head. He did not know that he could go so far as that; but certainly with electricity steeper gradients were possible than with locomotives, and much lighter trains could be run. The variations of gradient again caused no trouble. On many lines in Switzerland, as, for example, the line going to Grindelwald, it was necessary to change locomotives in order to keep the water at a proper level above the tubes of the locomotive; the locomotives had to be set on an incline to their wheel-base. All that was avoided by electrical propulsion. The question, then, resolved itself into one of cost. At the present day, was the cost really so prohibitive as it was in comparatively recent times? Large dynamos of 400 HP. or upwards could be had at a cost of something like £2 per HP., even if the dynamos had to run continuously or for a considerable length of time. If they were run intermittently, or comparatively intermittently, as they would be for propulsion purposes, they could be obtained at a much cheaper rate, because they could be loaded more heavily. The turbines, if the falls were favourable and not too low, could be had for something like the same cost, so that altogether the supply of power need not cost much more than from £4 to £5 per HP. To that, of course, would be added the cost of conductors; but if high potentials were used, say 2,000 volts, the cost of the conductors would not be very great, even though the distance were considerable; and the power could be transmitted to a considerable distance, say 5 miles, without serious loss. It might be said that the loss of pressure would be about 70 volts per mile, and, with 2,000 volts pressure a distance of 5 miles would not entail any very serious loss of power. The St. Gothard Railway might perhaps be taken as the one of all others which would be the most formidable to deal with electrically; but he had very little doubt that at the present day it would be possible to do the traction upon that railway more cheaply by electricity than it was now done by steam. The water-power was there, and turbines and dynamo machines could

Dr. Hopkinson.

be put in almost at any point upon the River Reuss, and the current could be supplied to the conductor along the rail as frequently as might be desired. Thus it would be possible to work at any pressure that might be needed. Possibly it would be prudent to run trains of somewhat less weight at more frequent intervals; but he doubted whether it would cost the undertaker any more than to run heavier and less frequent trains, and in that way a better public service would be provided. However that might be, it was clear that in the smaller class of railways, where the loads were light, the trains could be more frequent. In new railways there was not the formidable question of a larger plant that would have to be set aside. Electrical railways had before them a great future, and ought, he thought, to supersede steam for purposes of that kind. If that were done, he was sure that engineers would earn the thanks of climbers and tourists.

Dr. Preller.

Dr. Du Riche Preller stated that he was more or less intimately acquainted with almost every mountain or steep railway hitherto constructed in Europe. Having been closely identified with the subject, he might be allowed to make a few comments on the Papers. With regard to the St. Gothard Railway, the working and extension of which Dr. Preller had described in *Engineering*, Mr. Berg had omitted certain essential features, and his Paper also contained some statements which were certainly not borne out by experience. As to avalanches, Sir Guilford Molesworth had traversed the statement that forest plantations were a protection against them. It might be added that only last week a tremendous avalanche had blocked the St. Gothard Railway at a place where there was a good deal of forest plantation on the slopes. Moreover, if the Author would consult some of the works on avalanches that had appeared in Switzerland, he would find some interesting illustrations of the terrible havoc made by avalanches crashing through forests. The average cost of removing snow and ice on the St. Gothard averaged £6 10*s.* per annum per mile of open line; but in some years, as, for instance, the year before last it was as much as £10 per mile. The Author had not mentioned two very important extensions of the St. Gothard Railway. One was from Immensee, shortening the distance to Lucerne, and the other from Goldau to Tug, to shorten the distance to Zurich. The estimated expenditure for those extensions, 18 miles in length, would be £800,000. He might mention that the cost of alpine-tunnelling had been reduced since the Mont Cenis tunnel was first made. That tunnel had cost

Dr. Preller. £143 per yard, the St. Gothard £103, and the Arlberg £85. He believed the Simplon tunnel would cost still less. The reduction was not owing to the greater facility offered by the strata that were pierced, but simply to the greater rapidity of execution in consequence of the great improvements made in the machinery. He wished to call attention to the rail section used in the tunnels of the St. Gothard Railway, weighing 96 lbs. per yard. It had an equal moment of resistance and bearing capacity, with the 100-lb. Goliath rail used on the Brussels and Namur line. With regard to the duplex-compound goods locomotives on the St. Gothard Railway, which the Author said weighed 84 tons in full working order, as a matter of fact the weight was 87 tons. The water in the tank and boiler weighed 13½ tons and the fuel 4½ tons. It had been stated by Mr. Berg that the engine had given very satisfactory results, but the reverse was the case, for the results had been most unsatisfactory. The consumption of fuel on the gradients of 1 in 40, was no less than 160 lbs. per engine-mile, the average being 67 lbs. per engine-mile, which was no saving compared with the eight-wheel tender-engine of 80 or 85 tons, of which there were about thirty on the railway The Mallet engine was not only duplex but very complex. It had a tractive force only one-tenth of its weight. Another point which the Author had altogether omitted was that of the express compound passenger engines which had been running on the St. Gothard Railway for the last six months. They weighed 100 tons and hauled 100 tons (the train consisting of ten saloon carriages) from Lucerne to Chiasso at an average speed of 40 miles an hour. On the valley sections and through the summit tunnel the maximum speed was 64 miles an hour. This was about double the speed of the Mont Cenis, Arlberg, Brenner and Semmering railways. By means of those engines the running time from Lucerne to Chiasso would be reduced from six and a half to four hours. In regard to the point raised by Mr. Carruthers as to the rack being very much preferable to adhesion on a railway like the St. Gothard, he thought it was a great mistake. Mr. Abt was himself one of the directors of the St. Gothard Company, and he would be the last to recommend the rack for such an international highway. The rack, especially the Abt rack, was admirably adapted for such countries as Japan, New Zealand, Australia, Greece, the Balkan Peninsula or Asia Minor, where the Beyrout to Damascus line across the Lebanon was now being built; but for great international highways he thought adhesion should always be preferred. With reference to the Stanzerhorn Rail-

Dr. Preller.

way, he was sorry to notice that through all the three Papers the word "electricity" was only once mentioned, and therefore he welcomed Dr. John Hopkinson's remarks on the subject. The principal feature of the Stanzerhorn Railway he thought consisted in its being worked by electricity. It was the outcome of two other electrical lines constructed by the same enterprising firm of Bucher and Durrer, who introduced electric traction on mountain cable railways. One was from Lake Lucerne and the other from Lake Lugano, and both lines were worked by electricity from a central station with fixed motors. They also had the Abt rack, which on the Stanzerhorn Railway had been left out. He did not think that for the sake of say £3,000 the rack should be left out, if it was only for the feeling of security which passengers derived from such an element of safety. It was stated in the Paper that the power-station of the Stanzerhorn Railway also supplied other consumers. These were two other railways, one an electric road-railway from the Lake of Lucerne into Stanz, which was at the foot of the line, and another the Bürgenstock line. Standing on the summit of the line one could see about 5 miles away, far down the valley, a red speck which was the power-station itself. There was a low-pressure turbine which drove six dynamos, two for each line. Another essential feature of the Stanzerhorn line was that, owing to the superiority of its electrical traction, it had become a formidable rival to the Pilatus Railway, which had a gradient of 48 per cent., nearly 1 in 2, and was worked with a special combination of steam-cars weighing about 12 tons. The average saving by means of electricity, between the two lines, was 36 per cent. in construction, 50 per cent. in load, 50 per cent. in working, and 50 per cent. in repairs. It therefore came to what he had already maintained, that any electrical line could be worked at 50 per cent. less than the working cost of steam. Mr. Collett had not stated what was the working cost of the Montserat line with gradients of 15 per cent. Dr. Preller believed it to be 3*s.* or 4*s.* per train-mile. He would undertake to work that line electrically for at least 50 per cent. less. He was an admirer of the rack-engine pure and simple—he referred especially to Mr. Abt's, because that engine had been reduced to its very simplest elements, and it developed so much power that a 17-ton engine did for a short time the work of a 50-ton engine. But still electricity was superior, and he would prove this point by a comparison between the Mont Salève electric rack-railway near Geneva, having gradients of 1 in 4, and the Glion rack-railway,

Dr. Preller. with gradients of 1 in 4·7 working with steam locomotives starting from the Lake of Geneva at a higher level. The lengths of the lines were about the same, and the number of passengers was about the same. The Glion line was worked at 6·3*s.* per train-mile, and the Salève line for 3·2*s.* The load on the Glion line, with 50 passengers, was about 26 tons, and on the Salève line the same number of passengers was carried, the motor-car weighing 12 tons—an advantage of more than 50 per cent. With regard to the Japan Railway the result of the working on that line had not been satisfactory, owing chiefly to the locomotives, though it was difficult to say where the fault lay. The initial mistake, in his opinion, had been that instead of making the line like the Brunig Pass Railway, with a much steeper incline, 1 in 7, or an adhesion incline with gradients up to 1 in 20 or 1 in 16, a so-called combination line had been made which was the fashion at the present moment. It had been stated by Mr. Tomkins that in the northern suburbs of the metropolis a rack railway was unnecessary. No one would be so foolish at the present time as to lay down a rack railway to Hampstead Heath or Highgate, if a line had to be made there, as no doubt it would be in due time. Such gradients as 6 to 8 per cent. up to Hampstead Heath could be worked perfectly well by adhesion with electricity, and were so worked at Florence, Genoa, Zurich, Marseilles, Kief, Richmond, U.S., and other places.

Mr. Worthington. Mr. EDGAR WORTHINGTON, without attempting to compare in detail the relative general advantages of different systems of mountain railways, wished to offer some remarks on the methods of dealing with various classes of mountain traffic in some foreign countries. In order to present another aspect of the various methods of traction, he had arranged them in the order of their speed of surmounting vertical heights. The figures in the Table (p. 100) had been compiled mainly from his own observations of single journeys, but in each case the load hauled had been sufficient to test fairly the daily work of the locomotive. Several examples had been added from the three Papers under discussion.

It would be seen from this Table that the most rapid method of crossing mountains was by a cable-drawn car, which rose about three times faster than one drawn by a rack-and-adhesion locomotive. Cable railways were, however, not suitable for heavy traffic, and Mr. Berg had brought before the notice of the Institution some beautiful examples of Swiss scientific engineering which were a great advance on the cable traction of former times, even on those

interesting cable-worked inclines of Lisbon, Oporto, Hong-Kong, San Francisco, Cincinnati, and other places. The speeds (pp. 11 and 12) at which the two upper reaches of the Stanzerhorn Railway were worked considerably exceeded those he had observed in Hong-Kong and other places. The freedom from mechanical failure on those and other Swiss mountain railways reflected much credit on their constructors, and in his opinion was achieved largely by the thorough and methodical experimental testing of important materials, especially of the cables, which had been carried out in a very exhaustive manner, to the advantage of the manufacturers, by Professor Tetmajer, of Zurich, and his thirty able assistants, some of whose experiments were witnessed by the advanced students of the Polytechnic School. Next to cable railways, in order of vertical speed, came the pure rack railway, which was also more frequently used for light passenger traffic, as at Montserrat and Pike's Peak, than for goods traffic; but when the rack was made continuous for special conditions, as in the Puerto Cabello Railway, quoted by Mr. Collett, a load of 67 tons was pushed up 1 in 12 at a vertical speed of 3,000 feet per hour. Animal power was used largely on the excellent roads of India for reaching the hill stations, and the usual vertical speed of the mail tonga in the Neilgherry Hills was about 2,160 vertical feet per hour, in which a pair of ponies, changed every 4 miles, hauled a two-wheeled tonga laden with five persons and heavy mail-bags. A good mountaineer on foot could climb about the same speed as the average of the fourteen representative examples of adhesion mountain railways of gauges varying between 2 feet and 5 feet 6 inches. The weights hauled on mountain adhesion-railways depended on the size of the locomotive, and therefore on the gauge, but the average speed in daily work of those examples was 1,902 vertical feet per hour. Excluding the two examples of heavy goods trains hauled by "consolidation" engines with small wheels, the limit of load for one locomotive on such gradients as 1 in 40 appeared to be about 140 tons on either 3 feet 6 inches, 4 feet 8½ inches, or 5 feet 6 inches gauge. On the Western Ghât inclines of the Great Indian Peninsula Railway two eight-wheels-coupled tank engines hauled loads varying between 173 and 258 tons, while three locomotives were necessary on the Kicking-Horse Pass of the Canadian Pacific Railway and the Horse-Shoe Bend of the Pennsylvania Railroad. The low performance mentioned by Mr. Pownall on the occasion of his crossing the Kicking-Horse Pass might have been exceptional, for the Canadian Pacific Railway

Mr. Worthington.

Mr. Worthington.

COMPARATIVE SPEEDS OF ASCENT OF MOUNTAINS.

Railway.	Gauge.	System.	Gradient.	Height Surmounted Per Hour.	Average.	Daily Load Excluding Engine.
	Ft. Ins.			Feet.	Feet.	Tons.
Hong Kong	4 8½	Cable	..	7,500		.. [5]
	Metre.					
Stanzerhorn [1]	1	,,	1 in 12·5–1 in 3·7	4,100	7,325	.. [5]
,,	1	,,	1 ,, 2·5–1 ,, 1·6	7,900		.. [5]
,,	1	,,	1 ,, 2·5–1 ,, 1·6	9,800		.. [5]
	Ft. Ins.					
Puerto Cabello [2]	3 6	Rack	1 in 12	2,960		67·0 [7]
	Metre.					
Montserrat [2]	1	,,	1 ,, 16	2,040		.. [5]
,,	1	,,	1 ,, 7	3,280	3,290	.. [5]
,,	1	,,	1 ,, 4	4,090		.. [5]
	Ft. Ins.					
Pike's Peak [2]	4 8½	,,	1 ,, 4	4,090		.. [5]
Darjeeling [2]	2 0	Adhesion	1 in 28–1 in 22	2,000	*	27·0 [7]
Altoona and Northern (U.S.A.)	3 0	,,	1 in 25	2,600		50·0 [7]
Cantagallo, Brazil [2]	..	,,	1 ,, 12	3,830		40·0
La Guaira-Caraccas [2]	3 6	,,	1 ,, 27	2,450		51·5 [7]
Gotemba, Japan [2]	3 6	,,	1 ,, 40	1,550		136·0 [6]
New South Wales	4 8½	,,	1 ,, 30	2,100 [12]		125·0 [4]
,, ,, ,,	4 8½	,,	1 ,, 40	1,580	1,902	284·0 [6]
St. Gothard	4 8½	,,	1 ,, 40	1,540		.. [4]
Canadian Pacific	4 8½	,,	1 ,, 22·2	1,680		245·0 [4] [10]
Pennsylvania	4 9	,,	1 ,, 55·5	2,000		330·0 [4] [10]
,,	4 9	,,	1 ,, 55·5	800		700·0 [6] [10]
Great Indian Peninsula	5 6	,,	1 ,, 36	1,300		173·0 [4] [10] [12]
N.W. Frontier, India	5 6	,,	1 ,, 40	1,300		80·0 [4] [8]
Usui, Japan [3]	3 6	Rack and adhesion	1 ,, 15	1,800		50·0 [7]
,, ,,	3 6	,,	1 ,, 15	1,650		60–70 [7]
Mostar-Serajevo [2]	..	,,	..	1,600		..
Hartz [2]	4 8½	,,	1 ,, 16·6	954	1,615	140·0 [7]
,,	4 8½	,,	1 ,, 16·6	1,430		70–80
Hartz and Eisernerz [2]	4 8½	,,	1 ,, 15·6	2,257		..

* The heights surmounted per hour by two horses drawing an Indian mail tonga with five persons and heavy mail-bags, and by a good mountaineer with no luggage, are 2,160 feet, and 2,000 feet respectively.

NOTE.—The loads and speeds given in the Table are those of the particular journeys witnessed by the speaker, supplemented, where indicated, by facts deduced from the Papers. The maximum loads are in several cases somewhat greater.

[1] See pp. 11 *et seq.* [2] See pp. 31 *et seq.* [3] See pp. 43 *et seq.* [4] Passenger trains [5] Light passenger traffic. [6] Goods trains. [7] Passenger and goods trains. [8] One locomotive. [9] Two locomotives. [10] Three locomotives. [11] Approximate. [12] The maximum load is 258 tons.

Mr. Worthington.

was about that time burning some newly discovered native coal on several of its mountain sections. In the following month Mr. Worthington had crossed the same pass when a train weighing about 245 tons was hauled by three heavy locomotives, having together eleven driving axles, up the 3¼ miles of 1 in 22·2 at a speed of about 6½ miles per hour, the average rate of vertical rise being 1,680 feet per hour. During a residence of some months at Altoona, he was much interested in observing the methods by which the Pennsylvania Railroad carried the enormous traffic of their main line over the Allegheny Mountains, the most difficult portion of which was the well-known 12-mile length above Altoona. After forty years of experience, the present method was to use the ordinary four-wheels-coupled locomotives for the passenger trains and eight-wheels-coupled for the goods. The gradient was about 1 in 55·5, and three locomotives were usually required to maintain the necessary speed with ordinary trains. On the occasion of his last visit the passenger train weighed 330 tons, and the ascent was accomplished easily at a speed of 22 miles per hour, each engine developing about 17 HP. per square foot of grate, and the goods train on which he travelled up the mountain at 9½ miles per hour with three consolidation locomotives weighed about 700 tons. Great care and attention had been given to the best methods of working this section, and although it was found that the engine resistance of the six-wheels-coupled did not differ widely from that of the four-wheels-coupled engine when both were exerting full power at 21 miles per hour, yet the four-wheels-coupled ran more easily at high speeds, and was therefore preferable on the adjoining sections of easier gradient. The Fairlie engine was still doing good work in certain localities; but for such places as the Kicking-Horse Pass there was a demand for a more powerful adhesion locomotive. Mr. Mallet's four-cylinder compound duplex 87-ton locomotive on the St. Gothard Railway seemed to be a step in that direction, but, as he had on a previous occasion[1] pointed out, compound locomotives were not suitable for slow and intermittent heavy traffic. The Table given by Mr. Collett on p. 35 seemed to indicate that the incline of 1 in 25 was the limit of adhesion working. He (Mr. Worthington) had ascended and descended that gradient with a compound engine and a load of 50 tons in Pennsylvania without difficulty, but on one of the islands in the neighbourhood of Kobe, Japan, an adhesion locomotive hauled provisions up inclines of 1 in 18 to a copper mine, descending with the ore; and in England,

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 40.

Mr. Worthington. steam trams worked up gradients of 1 in 14 occasionally. The real limit to the steepness of gradients worked by adhesion locomotives was the limit of safety in descending, which had been much extended by the introduction of continuous brakes. In this country such brakes enabled the heaviest express trains to travel at their highest speed down the Shap incline of 1 in 75 with perfect safety; and the addition of brakes to all the wheels on such gradients as 1 in 18 would probably render the descent safe at low speeds with the use of sand for emergency. During the period of fitting the Great Indian Peninsula Railway passenger stock with continuous vacuum brakes, those trains already completed descended the 18 miles of steep gradient, reaching a maximum of 1 in 36, in half an hour less time than the trains depending on the old hand-brakes alone. The counter-pressure brake described by Mr. Collett on p. 29 as "the Abt system," was widely used for descending steep inclines. The Baden State Railway used it both for adhesion and ladder-rack locomotives, and it was frequently made in this country for rack and for adhesion engines to work abroad. It would, perhaps, have been more correct to ascribe the introduction of that form of brake to Mr. Bissinger, late of the Baden State Railway, or to Mr. le Chatelier, both of whom worked it successfully many years ago. The friction caused by excessive lengths of rigid wheel-base was an important item in limiting the loads hauled on very tortuous mountain railways, and might be illustrated by the Darjeeling Railway, where curves were very frequent and occasionally of 75 feet radius. When he visited that railway the maximum loads hauled by the two locomotives named by Mr. Collett[1] were, for the 11-inch cylinder engine, with 5 feet 6 inches wheel-base, 36 tons; for the 10-inch cylinder engine, with 4 feet 3 inches wheel-base, 27 tons, the weights of the locomotives being 14 and 12 tons. That represented a train-load of 2·57 tons and 2·25 tons respectively per ton of locomotive. Those two engines had the same boiler-pressure, diameter of wheel and piston-stroke. The total weight of the older and lighter engine with its train was 39 tons. The total weight of the more powerful engine and train should be in proportion to its tractive-power or $\left(\frac{11}{10}\right)^2$ of 39 = 52 tons; but in practice the larger engine and train weighed only 50 tons, indicating that the additional friction due to increasing the wheel-base from 4 feet 3 inches to 5 feet 6 inches was approximately

[1] *Ante*, pp. 32 and 36.

Mr. Worthington.

represented by a loss of 2 tons of carrying capacity. Following the adhesion method in attaining vertical speed came that by combined rack-and-adhesion engines, with an average speed, taken from six representative examples, of 1,615 feet of vertical rise per hour. The comparative slowness of this method might be due to two causes: firstly, the large size of the boiler, rendered necessary by the absence of economical expansion and difficulty of maintaining its pressure due to the slow travelling, slow piston-speed and infrequent blast; and, secondly, the internal friction of the rack-gearing, both of which causes tend to increase the loss of power. The 200 HP. exerted by the rack-engine on the Usui Railway was at the rate of 11 HP. per square foot of grate-area, or less than one-half that obtained from the boiler of any ordinary fast-running adhesion engine. On the Khojak Tunnel line he had travelled with the Indian State ten-wheeled 18-inch-cylinder locomotive hauling a load of 160 tons, including engine, up 1 in 40 at 10·9 miles per hour, and during that daily heavy work the engine exerted 13·6 HP. per square foot of grate-area. In the case of the Pennsylvania Railroad, exact measurements taken from frequent indicator-diagrams and dynamometer tests had shown that 20·5 HP. were indicated and 17½ HP. developed at the circumference of the wheels per square foot of grate with maximum loads and a speed of 21 miles per hour, on the Allegheny incline. Other examples might be quoted showing even better results, all of which indicated that large boiler-power was required for slow-moving rack-and-adhesion engines. No one could visit the Hartz Mountain Railway without being pleased with the Abt method of working; but it should be remembered that the lengths of those rack sections were very short compared with those of the Usui and other similar lines. Comparing this system with that of the continuous or pure rack railway, the engines of the latter were simpler; but in two such engines of equal power the strain, and therefore also the wear, upon the rack teeth caused by the pure rack engine was about double that caused by the combined engine, which exerted only half its tractive-force upon the teeth and the other half upon the ordinary rail. The Usui Toge Railway was an instance to which either system of working might have been applied; but the pure rack system would have involved not only the laying of an additional 2 miles of rack to the terminal stations and loss of time by running slowly on those two miles, but also double the wear and tear upon all the rack bars. The accumulation of steam and products of combustion in the tunnels of the Usui Railway, alluded to by Mr. Pownall, was a serious difficulty. Mr. Berg had also referred to

Mr. Worthington. those gases as interfering with men working in the St. Gothard tunnels, but in that instance the trains themselves, running at 11 to 12 miles per hour, seemed to leave their own smoke behind. In Japan, however, a powerful four-cylinder locomotive moved at only 4·7 miles per hour through a tunnel 600 yards long, in which he could testify that the atmosphere became so foul and hot that those on the engine must resort to temporary respirators in order to support life. Even the foot-plate engine-lamps which burned freely in the open were frequently extinguished in the tunnels for want of oxygen. The means of overcoming that difficulty which were being taken in the new engines had already been referred to by Mr. Shervinton and Mr. Burnett, and if other means were required fresh air might be temporarily obtained from near the rail-level or other source. Among the smaller rack engines referred to by Mr. Collett was one in which the pinion was coupled to the adhesion wheels. He had examined some of those simple little engines while at work at the Oertelsbruch quarries, their duty being to convey stone over considerable lengths of adhesion-railway, encountering occasionally short lengths of the Abt rack. The tractive-force was intended to be divided between the pinion and adhesion wheels. When the engines were new the adhesion tyres were made larger than their mathematically correct diameter, and their tendency was to overtake the pinion. These tyres would wear until the tendency would be to lag behind the pinion. Considerable wear and tear might be expected to attend the frequent or continued introduction of that internal strain, but the principle seemed to be applicable to small engines running on short and infrequent bits of rack, such as might occur in quarries, and where the initial expense of a second pair of cylinders was of importance. The difficulties, described by Mr. Berg, of providing against avalanches were no doubt great, but the Alps afforded excellent foundations for the structures of the St. Gothard Railway. In the year 1893 the engineers of the Hurnai Railway to Quetta met with the almost insuperable difficulty of large masses of the mountain-side shifting and carrying the line with them. The railway traversed the side of a valley through the "mud gorge," where, especially at the season of his visit, May, the melting snow was causing frequent landslips. The line could not be maintained sufficiently even for the necessary adhesion of the locomotives drawing their usual trains on the steep gradients, and the train was several times brought to a stand through that cause. But a greater difficulty was with the foundations of structures. Short tunnels of circular section had been constructed through some of the mud-slopes.

They could alter their position as the mud moved. They might roll down the hillside, but always presented a uniform circular section in which the rails could be readjusted after any serious movement. Mr. Worthington.

Mr. Passmore. Mr. FRANK B. PASSMORE remarked that the subject of mountain railways must necessarily be of considerable interest to all engineers. To him it was of peculiar interest, as some twenty-six years ago he had been selected by Mr. James A. Longridge to work what was, he believed, the first mountain railway in Europe, the railway over the Mont Cenis. Later on, he had had charge of all the constructed government railways in New Zealand, under Mr. John Carruthers, who was Engineer-in-chief, and he had the opportunity of becoming acquainted with the Fell system on the Rimutaka incline, although it was not opened until after he had left the government service, and, subsequently, the engines that were now doing satisfactory service there were built under his inspection. He had never been connected with any other system of working steep gradients; but he had visited and studied the Abt system on the Hartz and the ladder rack at Rüdesheim and elsewhere, and also the rack railway up the Corcovado in Rio de Janeiro.

A suggestion had been thrown out that the term "mountain railways" should apply only to cases where special means were adopted for overcoming elevations. He considered that a most practical suggestion, and one which it would be well to follow. There appeared to be four systems adopted to achieve this end, which, taken in the order of their introduction, were—1, Rope-haulage; 2, the Fell system; 3, the Riggenbach ladder rack; 4, the Abt system. Each of these had its advocates, but the principles of all of them were so well known that he need not attempt to describe them. The first system might, he thought, be set aside as not suitable for railways except in short lengths, and even then he did not consider it as safe as either of the other systems, owing to the fact that an undiscovered flaw might exist in the rope which would cause it to break at some time, and either allow the vehicle to run down hill, or, as Mr. Francis Fox had described, the rope might rush down on to the lower car to the evident danger of the occupants. Besides this, the motion was exceedingly jolting and unpleasant. The Fell system on the Mont Cenis had been laid down during the construction of the tunnel, and the concession lapsed when the tunnel had been opened. The line had been taken up and, he believed, sent to the Cantagallo Railway in Brazil. The two Fell railways, before

Mr. Passmore. mentioned, were laid down under circumstances the very opposite to one another: that on the Mont Cenis under the most disadvantageous, and that on the Rimutaka incline under the most favourable circumstances as to climate. On the Mont Cenis line there were at times during the winter terrific snow-storms and avalanches to contend with. He had frequently had engines so completely buried in snow, that it was not known where they were until they were struck with the snow shovel. The rails were often covered with a layer of ice, which naturally interfered with the adhesion. The removal of snow was calculated at 4*d.* per train-mile. For some considerable time breakage of the compression screw, used for putting pressure on the horizontal wheels which were carried in cradles, caused trouble, and it was therefore often necessary to work the traffic as well as possible with simple adhesion only. The cause of the breakages had subsequently been discovered and the defect remedied. The gradient from Lanslebourg to the frontier was 1 in 12½, and the same obtained from the other side of the pass—La Grande Croix—to Susa, with curves of 132 feet radius. Up these inclines he constantly took, by simple adhesion only, loads equal to the weight of the engine at a speed of 5 to 6 miles an hour, while, with the centre rail, loads of double the weight of the engine were taken at a speed of between 7 and 8 miles an hour. The fuel used, coke and briquette, was 81½ lbs. per mile, and the total locomotive expenses including repairs were 4*s.* per train-mile.

On the Rimutaka incline, which was 2½ miles long with a gradient of 1 in 15, a load of 92 tons had been taken by an engine weighing 36 tons at 5 miles an hour, with an expenditure of 201 lbs. of coal and 134 lbs. of coke, or 335 lbs. of fuel per mile. The usual load was 60 to 70 tons, at a speed of 5 miles an hour, with an expenditure of fuel of about 103 lbs. per mile, the locomotive expenses being 3*s.* 10*d.* per train-mile. When the engine was used as an adhesion locomotive only, it took up a load of about 15 tons, not one-half the weight of the engine. That certainly did not compare favourably with the results obtained on the Mont Cenis Railway. He very much doubted whether the load of 60 to 70 tons could be taken with every train. With that system so much depended on the state of the rails. He had known the horizontal wheels slip on a greasy centre rail, even when all the pressure capable of being put on them was applied.

He would now make a few remarks on what he considered the disadvantages of the ladder-rack—the Riggenbach system. Special sections of rack had to be made for curves of different

radii, and for right- and left-hand curves. That must be exceedingly inconvenient and expensive for renewals and repairs. The construction of the rack was objectionable from other points of view. It was evident that, built as it was of many parts, the constant hammering of the pinion on the steps of the ladder must tend to loosen the steps that were riveted to the side channels. The lubricant used to reduce the friction between the pinion and rack would work into the joint, and thus have a tendency to allow the rack steps to turn, which was a serious matter, as the step of the ladder was trapezoidal. If a single step became loose or defective the whole section had to be removed, and, to put in a new step, the section had to be taken to pieces. There was a further danger that the constant hammering on the step would cause the side channel to split in the line of the holes. Those were not imaginary objections; they had been shown to exist after careful practical investigation. Another objection was that the ladder-rack retained the snow and caused it to be compressed into ice, to the detriment of the working. He spoke subject to correction, when he gave it as his belief that none of the Riggenbach lines worked in winter, except perhaps some small mining railways, as, for instance, that at Friedrichsegen on the Lahn, near Ems. Mr. Passmore.

Next came the consideration of the Abt system. One great objection that had been raised to it some years ago was that the rack and pinion would soon wear out, and, by destroying the pitch, cause an accident by over-riding. That fear had been shown to be entirely groundless, as the wear of the rack was practically inappreciable, and that of the pinion, after adjusting itself to the rack on curves, &c., was exceedingly small, even on lines that conveyed a heavy traffic. As he had laid stress on the conditions of working the other systems when dealing with snow, he might mention that he understood that on the Hartz, where a considerable quantity of snow fell, there had never been a stoppage owing to snow blocking the rack. The mode of placing the rack-rails, one in advance of the other, and the provision that the fore-and-aft pinion wheels were also differentiated with respect to one another, ensured a perfect grip of the pinion wheels under all conditions. There was no undue strain thrown on either rack or pinion on entering or leaving a tooth, and more than one tooth was always in gear. That ensured regular and smooth working, and no unpleasant shocks or vibrations were experienced, and slipping was an impossibility. It was, he thought, generally admitted that with a gradient of 1 in 40 the limit of economical working by adhesion alone was reached. He had worked lines with gradients of 1 in

Mr. Passmore. 30 and with curves of 5 chains radius; but he did not consider them economical. In dealing, therefore, with locations where the gradients exceeded the limit laid down, the engineer had to study and decide which system should be adopted, and how best to apply such system when decided on. It appeared to him to be a great mistake to treat individual instances from a general point of view. Each line presented special features of its own which must be taken into consideration in coming to a conclusion. To those who were opposed, either on principle or owing to prejudice, to the use of special systems of haulage, and preferred to adhere to the pure adhesion system, he would point to the object lesson given by the Pilatus Railway which ascended 5,341 feet in 2·6 miles. To reach the same point with an adhesion-railway, with a gradient of 1 in 40, would necessitate a railway 40½ miles long.

The consumption of fuel on rack-railways appeared at first sight extravagantly high. A closer study, however, showed the immense advantage to be gained by that system. Taking, for instance, the results of the Pilatus Railway, which, with a gauge of 80 centimetres and a length of 4·3 kilometres, rose with an average gradient of 38·14 per cent.; and the results of another railway in Switzerland, the Ponts-Chaux de Fonds Railway, which, with a metre gauge, rose with an average gradient of 1·6 per cent. It was found that in order to take a train to the same height as on the Pilatus Railway, with a gradient of 1·6 per cent., or say 1 in 62·6, would require a line, say, 100 kilometres in length. Now, taking the cost of fuel on the Pilatus Railway for 100 gross ton-kilometres, the result was £5 17*s.* 6*d.*, and for the whole line it would be £25 5*s.* 2*d.* for fuel. On the Ponts-Chaux de Fonds Railway, where the cost of coal might be taken at about the same, the expense for fuel for 100 gross ton-kilometres was, say, 8*s.* Therefore by adhering to that gradient to the top of Pilatus (necessitating a railway 100 kilometres long) the coal bill for the same duty would be £39 17*s.*; say, in round figures, 57 per cent. more. But taking the gradient at 1 in 40, the cost of laying 40½ miles at, only £3,000 per mile for an adhesion line, would be £121,500, whereas the Pilatus Railway cost £92,458—a saving of £29,000, besides the perpetual expense of maintaining and working, say, 38 miles of additional railway, and the repairs to rolling stock passing over that extra length of line. In the case of the Pilatus Railway, Col. Locher had adopted a rack bar laid horizontally in the centre of the track with rack teeth along each edge.

The arrangement of the teeth was similar to that of ordinary rack-and-pinion gearing, and it appeared to him that the Abt

Mr. Passmore.

system of differentiating the gearing (by that he meant setting the teeth of the rack one in advance of the other) would offer great advantages by obviating the jerky motion of which travellers on the Pilatus Railway complained, and which was evidently due to the clearance that was unavoidable in simple gearing. He would also call attention to what he conceived to be a mistake often made when comparing the relative merits of the pure adhesion and rack systems. The comparison was often made in train-miles or speed-tons. That was evidently not a fair mode of dealing with the question. To his idea the comparison should be according to a given load lifted to a certain height—say foot-tons—and he was glad to see that Mr. Collett had given a Table showing comparisons in that sense. After careful study of the various systems before alluded to, he had come to the conclusion that the Abt system now held the field. It was of course a question whether in certain cases it would not be more prudent to adopt the pure rack instead of the combination system, as was done by Mr. Abt in the case of the Monistrol-Montserrat Railway; and with regard to the Usui Toge Railway he believed better results would have been obtained by the pure rack system alone, owing to the fact that the adhesion in the tunnels is particularly bad. A very pertinent remark had been made by Mr. Francis Fox to the effect that it was not necessary only to consider the question of taking up a load, but also that of safety. In that respect he would mention the difficulty there had been on the Mont Cenis with regard to brakes. Besides the ordinary brakes the engine and each wagon was furnished with cast-iron brakes to grip the centre rail, somewhat on the principle of the parallel ruler. The trouble was not only to take the trains up the inclines, but to get them safely down; and when the rails were greasy and the hold consequently bad, he had seen the cast-iron brake-blocks black hot; during a single trip he had known them wear away more than $\frac{3}{4}$ inch. That pointed to the danger of the train getting beyond control. With the Abt system and the use of the pinion-brake such a contingency was practically impossible.

With regard to the locomotives, he was sure that the Abt engine was a far more simple machine than the Fell, and although the latter, when well constructed, gave good results, he thought it was always preferable to adopt machinery of simple construction when it would do equally good work. The repairs must necessarily cost less. On referring to Mr. Collett's Table,[1] the following figures

[1] *Ante*, pp. 38 and 39.

Mr Passmore. would be found, to which he had added the corresponding figures for the Usui Toge Railway:—

—	Rimutaka. No. 17.	Eisenerz. No. 18.	Oertelsbruch. No. 20.	Usui Toge.
Gradient. . . .	1 in 15	1 in 14·7	1 in 12·5	1 in 15
Weight of engine .	36 tons	55 & 59 tons	23½ tons	33·45 tons
Gross load hauled, excluding engine	63 „	110 „	50 „	65 tons (mean)
Load drawn per ton of locomotive. .	1·67 „	2·00 „	2·17 „	1·94 tons
Speed is not given, but believed to be	5 miles per hour.	5·59 miles per hour.	5 miles per hour.	4·7 miles per hour.

This appeared to him to point to the superior value of the Abt system as laid down at Eisenerz, Oertelsbruch, and Usui Toge, although the latter was not doing what might be expected of it.

He was surprised to see in Mr. Pownall's Paper that the load taken with a 33½-ton engine was only 60 to 70 tons at a speed of 4·7 miles per hour. That only represented a mean of 1·94 ton per ton of engine, and he thought there must be some cause for this other than that offered by Mr. Pownall in his Paper. Mr. Pownall appeared to lay great stress on the fact that the ratio of grate-area to heating-surface was as 1 to 43·5 in the Usui Toge locomotive; but he would call attention to the fact that it was only as 1 to 40 in the Oertelsbruch engine, which took 2·17 tons per ton of locomotive at a higher speed up a gradient of 1 in 12·5.

Knowing from experience how essential it was to train men for such special service, he would like to know whether the drivers were instructed in the proper use of the engine, or whether they were left to find out all about the peculiarities of the system for themselves. If the latter, he could quite understand that they had even yet not learned all they would require to know before they got all the service out of the engine that it was capable of giving.

With reference to the remark made by Sir Douglas Fox as to the pushing of more than one carriage before the engine, he could not see what danger could arise from pushing two or more cars in front, if the cars were properly constructed. On the other hand, there was an element of safety in the fact of the engine being down hill, as it entirely did away with the danger of broken couplings. As a matter of fact, in most cases the engine was not coupled to the cars at all, so that, even were anything to happen to the engine, the carriages could be brought to a standstill independently by means of their own brakes.

Mr. F. C. Fairholme asked to be allowed to add a few observations on Mr. Pownall's Paper and on the interesting discussion which followed. It had been stated by Mr. Pownall that an incline of 1 in 15 was regarded by some of the Continental engineers, best qualified by experience to give an opinion, as too steep for profitable working even with a rack; but Mr. Pownall omitted to say that this held good only for railways having a heavy traffic. It was obvious that the heavier the trains and, at the same time, the greater their speed, in order to accommodate the traffic, the easier must be the gradient even with the rack. In thus easing the gradient, there came a point when the locomotive became, in order to give the large heating-surface required, of itself so heavy that its adhesion would suffice to work the train. Still, for the safety of the descending trains, it might even then be advisable to provide the rack; and this consideration would still limit the choice of gradients for pure adhesion working. The fact, therefore, scarcely needed explanation that no general hard and fast rule could be laid down as to the maximum rate of gradient for the rack; that must always be ascertained for each individual case. There were some other factors which had to be taken into consideration; the limit of strain on a steep incline, which the construction of the rolling stock will enable it to stand, the radius of curvature, having regard to the length of trains, particularly when pushed; the gauge, which was a predominant factor in limiting the size of the fire-box and grate, and consequently the power of the locomotive. To give an instance, the Oertelsbruch Railway in Germany had a gradient of 1 in 12½, and in that case it would have been a great mistake to have adopted an easier gradient. Trains of 50 tons were run over it at a speed of 5 miles an hour. The line had now been working fully eight years, and all that time a single locomotive had proved sufficient to deal with the traffic. On some days the locomotive was working fourteen hours, but that was exceptional, and might in time lead simply to the purchase of a second engine. Mr. Fairholme.

In the case of the Usui Toge Railway, however, Messrs. Rinecker, Abt & Co. also considered the gradient of 1 in 15 to be too steep for that particular case. Had Mr. Fairholme's firm been consulted about it in time, and had they been informed then of the large traffic to be expected, they would strongly have advised that 1 in 20 should not be exceeded, and that more especially, seeing that the narrow gauge admitted of only a small fire-box, as referred to by one of the speakers. Increasing the heating-surface by length-

Mr. Fairholme. ening the boiler would not meet the case, since experience had shown that the steaming capacity of a boiler was not materially affected by the plugging of a number of tubes, which pointed to the fact that the value of the tubes as heating-surface was comparatively small.

The two examples of rack railways just quoted should, he thought, show sufficiently how useless it was to theorize as to the best rate of gradient for rack railways in general, and that in this, as in many other instances, it was better to study the conditions of each individual case. He desired to call attention to a fact which was often lost sight of when speaking of the steaming capacity of the combination locomotive, namely, that owing to the exhaust of the four cylinders at short intervals into the same chimney, the blast was increased to such an extent as to cause the steaming capacity of the combination locomotive, running at, say, 5 miles an hour, to equal that of an adhesion locomotive running at twice and even three times that speed. In view of that fact there was a difficulty in understanding why, at the Usui Toge, it should be found necessary to employ forced draught, and he could not help thinking that that might account for a good deal of the smoke difficulty, to which Mr. Pownall had referred. The necessity had been referred to by Mr. Passmore (in order to obtain the best results with what was so essentially a special system, as a rack railway undoubtedly was as yet) that the engine-drivers and fitters for a new line should be given an opportunity of availing themselves of already existing experience, either by spending some time on a rack railway already in good working order, or by instruction from a competent man sent to teach them. The working of the Abt combination and pure rack locomotives was by no means difficult as soon as the men knew how to handle them, but a driver accustomed only to ordinary adhesion working would discover all sorts of imaginary difficulties which it would not take a rack man long to show him to be "mare's nests." It was impossible to give written instructions to cover all points, or even to foresee all the mistakes which were possible. Who could have imagined, for instance, that a driver would think that a lubricator provided for oiling the pinions, and thereby the rack, had to be fed with water—a practice which, as had been subsequently learned, actually occurred for some months at the Usui Toge.

Reference had been made by Mr. Sawyer at the last meeting to the fact of a rack engine being able to haul twice the load of an adhesion engine on the same road. If only the item "tractive force" were considered, the proportion was even greater. For

Mr. Fairholme.

instance, on a 1 in 6 gradient a rack engine was well able to transport a train of its own weight and more, whereas he very much doubted whether an adhesion engine could, as a general rule, even take itself up such an incline. But of course there was no magic in the rack, and where for a given power the factor "tractive-force" was increased, the other factor "velocity" must necessarily diminish in the same ratio.

A case of over-riding on a rack railway had been mentioned by Mr. Francis Fox. He did not mention the name of the line, but although he was glad to say that it was not one built on the Abt system, he thought it fair to mention that the accident, which was fortunately not a serious one, was, as he understood, due to an excess of caution in too much super-elevation having been given to the outer rail at a place where there were two reverse curves with only a short portion of straight between them. Under such circumstances any engine or carriage, even on an adhesion road, would be liable to derailment, but for more normal conditions he thought it was now generally conceded that, of all mountain-railway systems, the Abt, with its manifold and differentiated gearing, offered the maximum of safety. The method of comparing the relative efficiency of rack locomotives advocated by Mr. Holtham was, if he might venture to say so, somewhat misleading. In the case of light rack-engines, it was possible to make the effective heating-surface comparatively greater than in the case of larger and heavier engines of greater power, and therefore the former would always be at an advantage in such a comparison. In their case, namely, the fire-box could be made comparatively large and the tubes short, and that, as was well known, was favourable to the steaming capacity of the boiler, and therefore also to the power developed per unit of heating-surface—an item most intimately bound up with the weight of the engine. He must, however, also take exception to Mr. Pownall's figures, from which Mr. Holtham had made his calculations. The HP. of which the Usui Toge engines were capable (not that which Mr. Pownall's inexperienced drivers got out of them) was 294, which divided by 36 tons, the service weight of the engines, would give a constant of 8·17, not 5·51 as arrived at by Mr. Holtham. He would ask to be allowed to make a similar correction in the case of the Hartz engines where, with corrected figures $\frac{467 \cdot 6 \text{ HP.}}{56 \cdot 5 \text{ tons}} = 8 \cdot 2$, a figure very similar to the above, and, allowing for what he had said regarding lighter engines, also very similar to the constants arrived at by Mr. Holtham for the Montserrat and Trincheras locomotives.

Mr. Fairholme. With regard to the question whether it would not have been better to have built the Usui Toge as a pure rack railway, he was inclined to think that even on a fairly continuous steep gradient, where the adhesion could be in any way relied on, the balance of advantage was rather on the side of the combination system for gradients up to say 1 in 12·5. For, after all, the saving in weight of the adhesion-motor did not amount to very much—bearing wheels would always remain indispensable, and therefore the combination engine had only, as extra parts, one pair of cylinders and the motion, the weight of which would not amount to 2 tons. But, on the other hand, the advantage of the combination system was that the adhesion traction, to the extent due to the weight of the engine, was utilized for what it was worth, and that relieved the strain on the rack-rail, which could be made correspondingly lighter and less costly. Besides this, the necessarily expensive rack-switches were avoided, and the locomotive was capable, in case of emergency, of being used on the ordinary railway, as well as doing all the shunting in the yards or sidings. At the Usui Toge, for instance, the aggregate tractive-force required was a little over 10 tons; of this the adhesion motor could take 6 to 4 tons, according to the state of the rails, leaving only 4 to 6 tons for the rack. Of course in cases where the adhesion was entirely unreliable, owing to climatic or other influences—locusts, for instance—it was of no use considering it at all, but in such a case simple adhesion would be also seriously affected.

Mr. Findlay. Mr. C. F. Findlay wished to ask Mr. Collett a question with regard to his statement that the speed at present used on rack railways was somewhat low, being 6·2 miles per hour on 1 in 16, 4·35 on 1 in 7, and 4·1 on 1 in 4 inclines. Those speeds would appear at first sight to be very reasonable, and he conceived that they could only be modified either by increasing the weight of the locomotives or by reducing the weight of the trains. It would be satisfactory to know what Mr. Collett had in his mind in making that suggestion. With reference to the Usui Toge Railway, Mr. Carruthers had stated that he thought the Japanese Government were to be congratulated on having adopted the rack. Everything in the Paper rather pointed to the conclusion that a mistake was made in adopting the rack in that case. It appeared that the rack railway cost about the same as was estimated for an adhesion railway of 1 in 40, both being £300,000, and for an important through line of railway most engineers who knew anything of railway working would agree that it was a mistake to introduce a special system of working on one section in the middle of a trunk line of great

importance, unless some very important saving could be effected by doing so. There was a saving in distance, but no saving in construction. Although the line was shorter, there was considerable expense in maintenance, owing to the use of the rack, and it was so serious in regard to the first railway mentioned by Mr. Collett that the rack had been given up, and adhesion on such gradients as 1 in 16 was substituted. He thought it probable that by this time the mistake made in Japan, in adopting a section of rack in the middle of such an important trunk line as Mr. Pownall had described, had already been recognized. He would like to refer to one class of mountain railways which had scarcely been alluded to in the discussion, viz., mineral railways. The peculiarity here was that the traffic was all, or nearly all, down hill, only empty wagons having to be hauled up. A very successful incline for shipping nitrate had been built a few years ago, in which the old system of working entirely by gravitation was reverted to. The observation of numerous railways in the Andes had led him to the opinion that, in that region, the same system might with advantage have been much more largely used. Costly developments of 1 in 30 or 1 in 40 had been made, necessitating large annual expenditure in locomotive power, where the formation of the hills was such that a cheap rope incline could have been made, needing no motive power but the ore carried down. The cases might be rare where this could be advantageously done, but they existed, and it was desirable for engineers surveying for such lines not to be prepossessed with the idea that the purpose of a railway was to enable locomotives to traverse it. Mr. Findlay.

Mr. A. J. Hamilton-Smythe observed that Sir Guilford Molesworth had questioned Mr. Berg's opinion to the effect that, almost all risk of avalanches might be disregarded on a well-wooded hill-side. Perhaps he might be allowed to corroborate Sir Guilford Molesworth's criticism by the relation of an experience of his own of an avalanche which had occurred on a well-wooded hill-side during the construction of a railway in the Alps. At the place in question, the railway was formed in embankment about 7 feet high, along a strip of meadow lying between a river and a thickly wooded mountain. At about $\frac{1}{4}$ mile distant, at each side of the place in question, the railway crossed mountain streams, but, where the avalanche afterwards had occurred, there had been nothing more than a shallow depression in the contours of the mountain side, grown over with trees, undergrowth and grass, and with no sign of ever having been a water channel. In order to make a passage for cattle in and out of the piece of meadow enclosed between Mr. Hamilton-Smythe.

Mr. Hamilton-Smythe. the railway and the mountain, and also for surface drainage, the abutments for a flat-topped culvert about 5 feet span were set in the embankment. One night a violent thunderstorm, accompanied by torrents of rain, had broken over the district, and next morning he had found the railway embankments completely buried several feet deep in a mass of stony débris mixed with trunks of uprooted trees, while the surface of the space between the river and the mountain was filled up several feet above the level of the railway formation. The railway, when eventually re-formed, was in cutting instead of embankment, and a bridge was then substituted for the cattle pass, with an artificial channel excavated from the foot of the mountain slope to the river. For years afterwards, however, and probably up to the present day, no water of any account passed under that bridge. What seems to have occurred at the time was that a torrent far up in the mountains became temporarily diverted, for that occasion only, and swept down the new course, tearing a clearing through the forest and bringing down masses of débris until some combination of obstructions turned it back into its former channel. In the meantime the trees seemed to have had no practical effect in checking the avalanche. The moral he derived from that experience was that it was not safe to leave anything in the nature of a depression on a hill-side, such as might serve to concentrate an avalanche, unprovided for by sufficient works, even when the slope above and the dry channel itself was thickly wooded, as in this instance. A good way to deal with avalanches was to divert their courses and check their speed of descent by means of obstructive works on the hill-side inclined at angles to their lines of descent. If, as remarked by Mr. Carruthers, there were few mountains in the British Islands, there were a good many hills, and an extension of light railways would probably involve in some cases, though on smaller scales, some of the expedients used on mountain railways. On the St. Gothard and other similarly graded mountain lines, cork-screw arrangements seemed to have been used too freely for economy, in comparison with expedients involving sudden lifts by special means. Surely the weight of trains descending gradients might be more utilized than hitherto in pulling ascending trains uphill by the intervention of a wire-cable. A vast amount of useful power seemed to dissipate in the sparks thrown off by the braked wheels of trains descending steep gradients. He was not aware that any combinations of cable and adhesion traction had been tried on any important scale, but it seemed to him that even from adhesion alone the full benefit had not yet been

obtained which might be derived from it for steep-gradient railway traction. Mr. Hamilton-Smythe.

Mr. A. H. Whyte Butler said that, during the discussion, the Oroya Railway, Peru, had been casually mentioned by Mr. Woods, Sir Douglas Fox, and other members.[1] Having been engaged on the relocation and reconstruction of the portion from Chicla to Oroya, a few remarks from him might perhaps be worthy of attention. Undoubtedly the Oroya Railway (as far as altitudes attained were concerned) was unique of its class, viz., that of an adhesion-railway pure and simple. The railway attained an altitude of 15,665 feet above sea-level, at a point 106 miles from Callao, the starting-point, which was 8 feet above sea-level. That extreme height was reached in the centre of the Galera Tunnel, which was driven through a high ridge of the Andes; from thence it fell to Oroya, 30½ miles distant, the height of which was 12,178 feet above sea-level. The average rise per mile from Callao to Galera worked out at 147·7 feet, or 2·8 per cent.; but from Callao to San Bartolome the line only rose at the rate of 2 per cent., and from thence to Galera 3·4 per cent. Upon the section between Callao and San Bartolome there was nothing that he wished to mention in particular, except the very frequent destruction of certain parts of it during the rainy season, owing to floods from the River Rimac, slips, and washouts. He had been there in the winter of 1890–91, when damage to the line, between Lima and Chicla, was caused to the extent of about $120,000 (Peruvian currency), and traffic was suspended almost completely for over a month. From San Bartolome there were fifty-two tunnels, varying in length from 120 feet to 3,280 feet, which was the length of the Galera or summit tunnel. During one of the frequent washouts in 1889 the Verrugas Viaduct, a large iron trestle structure 580 feet long, in four spans, 250 feet high, had been carried bodily away, owing, to a great extent, to one of the trestles having been placed almost in the bottom of the gorge which the viaduct spanned. This had now been replaced by a fine cantilever structure having its two piers placed well out of the way of washouts, &c. It was designed by an eminent American engineer, and erected by Mr. A. Riffle, to whom the greatest credit was due for the expeditious manner in which it was carried out. Unfortunately Mr. Riffle had contracted a virulent local fever, which terminated fatally. There were no less than twelve V's (or switchbacks) on the division San Bartolome-Galera, five of them being above Casapalca. Up these the engine pushed Mr. Butler.

[1] Appendix to Mr. Collett's Paper, pp. 32 and 36.

Mr. Butler. and pulled the train alternately. The buffers were central, and no accident to his knowledge had ever happened through pushing, although three or four cars were frequently on the train. When he arrived in Peru in the early part of 1890, the line was being worked by ordinary adhesion engines of the Baldwin type, using coal as fuel; and it had been found that the greatest difficulty was experienced in keeping steam on the engines on the steeper inclines, more especially between Matucana and Chicla. He had frequently known the trains come to a complete standstill on this account. It was suggested that an oil-burning engine would keep steam better, and as a consequence one of the Baldwin engines was converted. This proved a complete success, no difficulty being experienced thereafter in keeping steam; it was therefore decided to convert all the mountain engines into oil-burners, and they had been running satisfactorily ever since. The oil was supplied from the petroleum wells of Talara in the north of Peru, which were worked by an English Company. It was the heavy oil remaining after extracting the illuminating oils. Experience had shown that 2 tons of oil did the work of 3 tons of coal; in some cases 1 ton of oil was equivalent to 2 tons of coal; but the former would be nearer the mark, taken as an average. The cost of the oil was about 30*s*. per ton, and of coal 24*s*. per ton, so that there had been a considerable saving on fuel account, combined with increased efficiency. The cost of conversion was about £25 per locomotive. The system used on the Great Eastern Railway was to his mind the most efficient system at present in practice, there being practically complete combustion. Holden injectors were used on the Great Eastern Railway, two to each engine. The great advantage of them was that, in case of failure, the core could be replaced in a few moments, a spare one being carried on each engine whilst in service, and that very little work was required to convert an engine, all that was necessary being to fix tanks on the tender, and to cut two circular 5-inch holes in the fire-box, about 10 inches above the fire-bars, one on each side. The cost of fitting one of their first-class express engines, including two cylindrical tanks, two injectors, connecting-tubes, fittings, &c., was about £75, the tanks having a capacity for a run of from 500 to 600 miles. For a narrow-gauge engine only one injector would be required and one tank. The engines could be reconverted in a very short time, it only being necessary to fill up the two holes in the fire-box. As a rule, it took three days to convert a locomotive, but during the great coal-strike of 1893 one had been converted in sixteen hours. Where liquid fuel could be obtained in

sufficient quantities, and relatively as cheap as coal, taking into account the efficiency ton for ton, it was undoubtedly more advantageous to burn oil, for several reasons. The fireman had almost nothing to do, and could assist the driver in keeping a look-out. The steam-pressure could be maintained perfectly steady throughout the journey, and steam be raised much more quickly. With coal from cold it took about one hour and three-quarters; with liquid fuel, one hour. There was always a clear fire and no smoke. Oil did not deteriorate by storage, whereas coal did, to the extent of one-twelfth in six months. Oil was less bulky than coal—1 ton oil, 35 cubic feet; one ton coal, 40 cubic feet. A thin layer of coal or breeze was placed at the bottom of the fire-box, which became incandescent, thereby igniting the oil. The fuel was injected into the fire-box by means of jets of steam and atmospheric air, which broke up the stream and distributed the flames over the fire-box, thereby preventing local heating. The prices of liquid fuel and coal were as follows:— Mr. Butler.

		£	s.	d.
Coal-gas tar	per ton	0	12	6
Oil-gas „	„	0	8	0
Creosote oils (average)	„	1	5	0
Petroleum	„	2	0	0
Petroleum refuse, crude and refined . .	„	2	0	0
Coal	„	0	16	0

It would be readily gathered from this, why liquid fuel was not more generally used, viz., on account of scarcity and price. Taking a month's averages on the Great Eastern Railway of one engine burning coal at 16*s.* per ton, and another burning oil at 25*s.*, the following results had been obtained:—

1st average, coal only	35·4 lbs. per mile =		3·03*d.*
2nd average, coal for lighting, &c. .	11·8 „ „	= 1·01*d.*	
„ liquid fuel	10·5 „ „	= 1·41*d.*	
	22·3 „ „		2·42*d.*

So that it did not pay to burn liquid fuel when its price exceeded 36*s.* per ton, coal being at 16*s.* per ton; those fuels which he had quoted at lower figures were not readily obtainable in large quantities.

The following details of the Oroya Railway might be of interest: Gauge 4 feet 8½ inches; minimum curve 120 metres radius; maximum gradient on tangents, and curves of 300 metres and upwards, 4 per cent.; on 120-metre curves 3 per cent.; between 120 metres and 300 metres, proportional; tangents between reverse curves not less than 50 metres; engine fitted with steam-brakes;

Mr. Butler. each car fitted with independent hand-brake; no continuous brake; flanged rails, of steel, 70 lbs. per yard; four spikes to each sleeper; sleepers, 8 feet × 8 inches × 6 inches, of redwood, 2,300 per mile; fishplates 40 lbs. per pair, curved under flange; all cars of American build, fitted with bogies.

Mr. Collett. Mr. A. Collett, in reply, said that on behalf of Messrs. Pownall, Berg and himself, he had to thank the Institution for the kind way in which the Papers had been received. An example had been given by Mr. Sawyer of twice the load being hauled on a similar incline to the Kicking-Horse, which had been specially referred to by Mr. Carruthers, and he quite agreed with Mr. Sawyer and differed from Mr. Carruthers on that point. It clearly depended upon how the HP. was applied, and on the gradient not being too steep for the machinery employed. Taking the different loads hauled by different classes of engines, it would soon be found that it was not the load due to the HP. that was hauled in each case; for instance, the Oroya engine hauled 75 tons on a 1 in 22 gradient; on the Kicking-Horse incline 81 tons was hauled on a similar gradient; and on the Hartz Railway 120 tons was hauled up 1 in 16·6. A good rack engine would have little loss, but would utilize to good effect its HP. by the constant beat of its six pinion-wheels on the rack, while on a greasy road, an ordinary adhesion engine might, and often did, lose a great deal of its effective power through slip, especially on such a gradient as 1 in 22. He was glad to hear Sir Douglas Fox supported his opinion as to the system of rack. As it was interesting to know what difficulties had occurred, he might mention that when last on the Petropolis incline in Rio de Janeiro, he found that the slipping of the rack-road down hill caused a good deal of trouble to the maintenance gangs, and it could be imagined how a hot tropical sun assisted such sliding of the road; this was prevented on some railways by the system of anchoring described in the Papers.

As to placing the engine between the two carriages of a train, personally he should much prefer to be pushed up an incline, and hauling was certainly not advisable in cases where a pinion ran on a carriage axle for brake purposes, as on the Montserrat Railway. It would be seen from the section (Plate 2), that that railway commenced with a descent of 1 in 16; the engine used formerly to descend at the upper end of the train, so as to be in readiness on the return journey to haul the train up the 1 in 16 incline; but the vibration was such, that it was found best to change the engine in the valley, and always have it below the train; the vibration seemed to be caused by the draw-bars giving, and causing the

carriage-pinion to run roughly in the rack. He noticed that on the splendid São Paulo incline, a very practical method was employed to keep the train together. A powerful chain was passed right round the train, so that neither the action of the powerful brake-van nor the haulage of the cable could separate the cars. The question of speed had been referred to by Mr. Burnett; this was certainly of great interest. Speed on many foreign lines was not a great object. The management tried to make a line commercially a success, by hauling as large a load as possible, without much regard for speed; and even in North America on some inclines one could walk as fast as the train. It seemed curious at first that the speed in the ascent of steep inclines was frequently greater than that of the descent, but caution naturally imposed a limit upon the speed of descent. He observed that Mr. Holtham divided the HP. by the weight of the engine, and advocated that method, but unexpected results were arrived at, and they were certainly not satisfactory. A similar factor had been obtained for the Montserrat engine which hauled 24 tons up a 1 in 6 gradient, as for the Cantagallo engine, and actually a smaller factor for the Hartz engine, while Mr. Collett gave 1·41 for the Montserrat, 1·26 for the Cantagallo, and 2·14 for the Hartz; in no case could the efficiency of the Cantagallo engine on the incline be considered equal to that of the Montserrat engine and superior to that of the Hartz engine which hauled 120 tons up 1 in 17. As far as he could see, Mr. Holtham could only take the speed into account by the reduced pressure in the cylinder, but he thought he had said enough to show that the method was unreliable. The method Mr. Collett had adopted was a simple and practical one, and had the advantage that any engine-driver or traffic manager could take out the results himself for purposes of comparison. With regard to a limit of gradient for mountain railways which had been alluded to in the discussion by several members, the Governments of Uruguay, the Argentine Republic and Brazil, had fixed 1 in 50 for the limit gradient of ordinary lines, while in England he thought engineers considered 1 in 40 to be the limit; for purposes of general comparison he had therefore commenced with 1 in 45. Allusion had been made by Mr. Francis Fox to the important matter of safety; the owners of mountain railways had had to be very careful; they knew that any serious series of accidents might lead to the total closing of their property. They were, therefore, most careful to keep their trains well under control in the descent, and used the various brakes, automatic and otherwise, already described. To prevent

Mr. Collett.

Mr. Collett. the pinions mounting the rack, there were methods employed on some mountain railways, but they were inconvenient in many respects, and were not considered to be necessary with the Abt rack. In answer to Mr. Head, he might mention that the load taken by the Cantagallo engine did not include the weight of the tender and pony truck in front, but that, adding the weight of the tender to the load hauled, and the weight of the water and coal carried by the tender to the engine weight, gave a factor of 1·26 ton hauled per ton of engine weight.

Interesting remarks had been made by Dr. Hopkinson and Dr. Preller about electrical traction. Mr. Collett, however, did not consider that the question of cost was as much in favour of electrical haulage as Dr. Preller suggested, and that even the Mont Salève electrical line did not compare very favourably in this respect with the Montserrat Railway, taking Dr. Preller's cost of working per train-mile. It was true that a light electrical motor of between 8 tons and 12 tons compared to a pure rack engine of between 17 tons and 24 tons showed a certain advantage in favour of electrical haulage as regards the load to be hauled up an incline, but Mr. Collett thought that Dr. Preller made rather a bold statement when he said that any electrical line could be worked at 50 per cent. less than the working cost of steam. He considered that, as in other methods of traction, each individual railway must be judged on its merits, and that such a statement as the above was not justified by electrical experience to this date. Moreover, as regards electrical motors, it was proposed that on the Baltimore and Ohio Railway they should weigh 95 tons each[1] and should haul a load similar to that hauled by the largest steam-engines. He did not see much economy in comparison with a steam-engine, in capital and working, in that case. In answer to Mr. Worthington's remark that "cable railways were not suitable to heavy traffic," Mr. Collett considered that they were in many cases very suitable for heavy traffic, and few better examples of cable traction could be found than the São Paulo inclines with their 700,000 tons hauled annually. As regards the counter-pressure brakes, Mr. Collett was under the impression that the steam-brake on the Petropolis Railway had been introduced by Mr. Le Chatelier. The weight of the locomotive was not included in the train load given on the Darjeeling Railway, but it would be noted that these little engines with their 2 feet 2 inch wheels had a very great piston-speed.

The wear of the rack had also been mentioned by Mr. Worthing-

[1] *Electrician*, Feb. 1, 1895.

ton. As had been stated in the Paper and in the discussion, the wear was inappreciable; on the other hand there was often far more wear on the rails of steep adhesion lines, due to the use of the brake in the descent, than on any part of a rack line. The motion of cable railways was described by Mr. Passmore as exceedingly jolting and unpleasant, but Mr. Collett found that on the São Paulo inclines the motion was not at all unpleasant. The remarks in the Paper on the Fell system were confirmed by Mr. Passmore from his experience on the Mont Cenis Railway, his remarks on coal consumption being very interesting, and he showed that the apparently heavy consumption of coal on a pure rack line was less than would be the case if a long adhesion gradient had been adopted to reach the same height. Mr. Collett.

Attention had been also directed by Mr. Passmore to the small load hauled by the Usui locomotive. Mr. Collett had noted this and would be glad to know the reason for it. It certainly appeared that a grave mistake had been made in the choice of a gradient and in the location of the line with such heavy works. It had been remarked by Mr. Fairholme, that on the Usui Railway Messrs. Rinecker, Abt and Co., would have advised that a 1 in 20 gradient should not be exceeded; that seemed to show the advantage of the table of comparison, giving the load hauled in connection with the gradient. In answer to the remarks about gradient made by various speakers, Mr. Collett considered that present practice showed that it was generally found that the maximum gradient for ordinary engines was from 1 in 30 to 1 in 40 according to the climate; that specially constructed adhesion engines had their economic limit-gradient at about 1 in 25; the Fell centre-rail engine about 1 in 13; the rack-and-adhesion combined from 1 in 25 to, say, 1 in 7 according to circumstances; and the pure rack and wire-rope from 1 in 16 to 1 in 4. Of course the above was only a general guide, and each case must be judged on its merits, being to a great extent ruled by the length of incline, climate, &c.

It had been asked by Mr. Findlay what Mr. Collett had in his mind in making the suggestion that the speed at present used on the rack was low. Mr. Collett considered that, looking at the speed from a passenger's point of view, the speed was low for long inclines, and he was of opinion that means would have to be taken to increase the speed on rack lines used for business purposes, such as the Petropolis Rack Railway. As regarded Mr. Findlay's remarks on the use of adhesion on such gradients as 1 in 16, it must be borne in mind that the rack in this case which had been replaced by adhesion was of a very old type

Mr. Collett. and certainly not to be compared to the present rack appliances in any respect, and Mr. Collett did not think that adhesion was the most convenient or the most economical method of working that incline of 2⅓ miles of 1 in 17 between Madison and Indianapolis; in many cases of this nature a strong rack-engine used as a bank-engine would seem more economical. Unless the advantages were striking, Mr. Findlay would not place a special system in the middle of a trunk line. Now one of Mr. Collett's objects in collecting materials for his Paper was that he had found that there were many railways abroad on which a rack or other special system could have been used with advantage and economy if the Governments and engineers had allowed it. Moreover, railways might have been built, which on account of their cost in tunnels and other special works were now only projects. Another point was that there was naturally more mileage in branch lines than in main trunk lines, and on these branch lines, especially when they were being built to develop a country, there was generally great advantage in economy in the work. Mr. Collett would therefore recommend in the above cases that the difficulty be faced and steep inclines made.

In answer to the enquiries as to the cost of the works on the Montserrat line, Mr. Collett would estimate that a rack railway with similar works could be constructed and equipped for £12,000 per mile.

⁂ Mr. Pownall's reply to the Discussion will be found at the end of the article.

Correspondence.

Mr. Becker. Mr. M. J. Becker, of Pittsburgh, submitted information with regard to the rack railway mentioned by Mr. Collett at p. 25 of his Paper, between Madison and Indianapolis, which had been the first ever built.[1] The same incline, it appeared, was now worked by adhesion with perfect safety and with greater economy, speed, and convenience than with the rack formerly used. The incline was 7,040 feet long, averaging 1 in 17; but for about half the distance the gradient was 1 in 16·5, and in two places was, owing to settlement, even steeper; also, owing to slipping of an embankment, a curve had been introduced on the alignment originally straight. The rack was used from 1847 to 1868, but since that adhesion had been used. The locomotives now in use were two in

[1] See Appendix to Correspondence, p. 148.

number, with eight coupled driving-wheels and no other wheels. Mr. Becker. A trial trip with one of these engines (which had been originally built as a ten-wheel-coupled engine, and was reduced to eight wheels, 5 feet in length being taken off the frame) was made about eight years ago. The engine weighed 47 tons, and was able to haul a train weighing 219 tons (including the engine itself), but stopped after 500 yards. A trial was then made with four cars, weighing, together with the engine, 175 tons, when an average speed of 4·7 miles per hour was obtained. The tank, which was over the boiler, carried about 1,520 gallons of water, and the wood carried for fuel amounted to about three-fourths of a cord, or 96 cubic feet (dry beechwood). In tests made in 1875, before the above-mentioned alteration of the locomotive, the following results had been obtained:—Weight of engine, 50 tons; weight of train (eight coal cars), 137½ tons; total weight, 187½ tons; speed at foot of incline, 2 miles per hour; average speed of ascent, 6 miles per hour; steam-pressure, 130 lbs.; fuel used, 0·6 of one cord of dry beechwood. Another trip had been made with two passenger cars, weighing 39 tons. Total weight of train, 89 tons; speed on entering incline, 6 miles per hour; average speed, 14·5 miles per hour; steam-pressure, 132 lbs.; fuel consumed, 0·3 of one cord of dry beechwood. No want of adhesion had ever been experienced in any weather, nor had sand been used in the tests above described.

A patent had been granted in 1831 for a rack railway to one Ewer Rimber, in America, the original papers and drawings of which had come into Mr. Becker's hands when making inquiries on the subject.

Mr. H. P. Bell, of Victoria, B.C., offered information as to the Mr. Bell. practice adopted in the higher latitudes of North America in regard to the construction and working of mountain railways. One of the most important aids to the working of such railways in winter was the snow-plough. Leaving out of consideration the rotary plough, a type that had been much used might be described as an inclined plane below, surmounted by a ploughshare, or spreader, above. The toe of the plough was made of malleable iron or steel, and was hinged so as to be capable of being raised and lowered by a lever-handle from within. The toe dropped over the rails and removed the snow to a depth of about 2 inches below their heads, and two flangers attached to the fore-part of the cow-catcher (upon the locomotives making regular trips) completed the operation by removing the snow below the shoulder of the rail for some few inches in width, this last operation being necessary to prevent the effects of frost in a place where accumulation might

Mr. Bell. be a cause of danger. The toe was raised by the lever-handle at all planked road-crossings, and these were often marked by a signal-post to apprise the plough-conductor of their proximity.

He called attention to the necessity of subordinating hard and fast limits of gradients and curves to the natural conditions of the locality, in laying out mountain railways. In many years' work upon mountain railway survey he had never met with an instance where nature, if well studied, did not indicate the proper solution of any difficulty that arose. He could remember many cases where a long succession of sharp curves, with heavy work, would be required to establish a maximum gradient of 1 per cent., while a gradient of 2 per cent. afforded a direct line, with light work, upon the bottom flats of a valley sufficiently wide, but flanked in by precipitous mountains with tortuous base and occasional broken banks.

The switchback seemed to him a simple and economical resource, where the ground was favourable, even for a short distance. If laid out with an ascent at the lower end of each gradient, and operated with a locomotive at each end of the train, it offered an automatic protection to runaway trains, and might reasonably be considered safer than any continuous steep gradient involving sharp curvature to change direction. It would generally give easier curvature, and afforded a means of avoiding a bluff of rock or a steep ravine that might otherwise be an expensive obstacle.

He considered that there was much to be said for operating all mountain railways with two locomotives, placing one at each end of the train. Communication between the two drivers had been successfully maintained by means of the whistle, and, when the road was familiar to both, little signalling was required. A great advantage of this system lay in the fact that a smaller tractive force had to be transmitted through the couplings of the cars, and this led to a corresponding reduction of the flange friction in passing round curves. He mentioned a case of a serious accident in the United States, with a long train having two engines ahead, in which one or more of the cars left the rails on a curve of small radius, pulling the rest after them. The accident was ascribed to excessive tension. When a large portion of a long line had gradients that could be economically worked by a certain class of engine, it was an advantage to adopt on the steeper sections a gradient on which the same train could be moved by two similar engines. Where a maximum gradient of 1 in 40 occurred at intervals over the whole route, and, at one point only, a steeper gradient was required, it would seem good policy to introduce the switchback to secure uniformity, if the natural conditions allowed of it.

He agreed generally with the opinion that 1 in 40 was the steepest gradient that should be adopted for pure adhesion, but would remark that climate might modify the available adhesion very largely. He remembered having travelled on a gradient of 1 in 22, with an engine weighing in all about 40 tons attached to four empty flat cars. The engine came to a standstill four times in 3 miles of ascent, and only made a maximum speed of 3 miles per hour. This had been during the early hours of a foggy morning, when the rails were greasy. Mr. Bell.

Mr. Foster Crowell, of New York, observed that, among the methods of working mountain railways described in the Papers, there was no allusion to the use of geared engines,[1] of which a number were employed for that purpose in the United States. He therefore forwarded particulars of the Tiadaghton and Fahnastalk Railway, in Pennsylvania, for many of which he was indebted to Mr. C. B. Farr, General Manager of the Railway.[2] He also forwarded a map of the steep portion of the line, showing the switchbacks, a drawing of the Shay engine in side-elevation, and a photograph of one of them in service. The peculiarity of the Shay engine was that it had vertical cylinders, three in number, driving a horizontal fore and aft crank-shaft, gearing, by means of bevelled pinions, into the face of each of the wheels of the engine and tender. The crank-shaft had flexible telescopic couplings, so as to confine the rigid wheel-base to the length of one truck. The boiler was set to one side of the centre-line, so as to balance the machinery. Steam- or air-brakes were applied to all wheels. These engines had familiarly acquired the name of "stem-winders." Mr. Crowell

The railway above mentioned was a logging railway worked with the rolling stock of the main line, but separately owned. The Shay engine could run, if desired, on the main line, and do the shunting at the junction. On the level this engine could haul its limiting high-gradient load at a speed of 15 miles an hour. He had ascended gradients of 10 and 12 per cent. with engines of this type, but considered 6 per cent. the limit for economical working of main line traffic, though 8 per cent. might be used on branches to loading points. The speed in ascending, attained on this line, was upwards of 5 miles per hour.

The day's work of the engine was given as 70 miles, hauling,

[1] Minutes of Proceedings Inst. C.E., vol. cii. p. 386.
[2] Appendix to Mr. Collett's Paper, p. 37, col. 14.

Mr. Crowell. on the average (of up and down), 125 tons gross, with a coal-consumption of 5,500 lbs. He thought it obvious that, between the gradients suitable for simple adhesion engines and those suitable for the rack, there was a distinct field for this type. Other things being equal, a line built for this type of locomotive need only be one-third the length of a line of the ordinary type (taking 6 per cent. and 2 per cent. as the gradients for comparison on an ideal section). The cost would be less than one-third, owing to the smaller radius permissible on curves, and the facility thereby given for avoiding heavy earthwork, and owing, also, to the lighter rail that might be used.

In regard to the switchbacks, it might be interesting to note that, following a conspicuous authority, the tails were originally constructed on the same gradient (1 in 16·6) as the rest of the line, as a continuation of the line below the points, so that a descending train, after crossing the points, would lose its velocity in running into the tail. It was found, however, that the velocity with which a descending train had to enter in order to carry its whole length clear of the points was too great for safe working with this arrangement, and the gradient of the tails had been reduced to 3 per cent., that being about the gradient at which the engine could hold a loaded train by its own brakes or pull it up-hill. On this road the engine descended at the head of the train, by which means all the cars received the benefit of the sand used in slippery weather. On some logging roads it was thought better to have the engine behind the train, so that if control was lost, the engineman could uncouple and save his engine, the cars only being wrecked.

Mr. Fellmann. Mr. J. FELLMANN, of Lucerne, forwarded particulars of the Rigi railway.[1] Trial trips on this line were made on the 21st May, 1870, and it was opened for traffic the following year. The permanent way had originally been laid with timber cross-sleepers having longitudinal timbers notched into them. Iron sleepers had since been substituted, 7 feet 6½ inches long by 9 inches wide and 2·4 inches deep, with which the longitudinals were unnecessary. The track rails originally weighed 28·2 lbs. per yard, but had been replaced by heavier ones. The original rack, 4¾ inches in height, was still in use and showed little sign of wear.

Mr. Ferrar. Mr. W. G. FERRAR observed that Mexico furnished many examples of mountain railways. The Mexican Railway (4 feet

[1] *Ante*, pp. 20, 44, col. 32.

Mr. Ferrar.

8½ inches gauge) had a continuous gradient of 1 in 25 (uncompensated) for 16 miles, and reached a height of 8,400 feet above the sea. It was maintained in a high state of perfection, and the Fairlie engines used on it took their load of 120 tons round curves of 330 feet radius up the incline with the greatest ease and steadiness. Various single engines had been built for this work, but up to 1890, when he had left Mexico, none of them had proved successful, as they ran short of water. Rails of 85 lbs. per yard with steel sleepers were now used on the incline with economical results. The Mexican National Railway (3 feet gauge) from Mexico City to Laredo (Texas, U.S.A.) had 3 inclines on its 837 miles of main line. No. 1, about 17 miles long, reached a level of nearly 10,000 feet above the sea, with an average gradient of 3½ per cent. and curves of 260 and 300 feet radius. No. 2, in the opposite direction, had 10 miles of 4 per cent., compensated. No. 3 averaged 2 per cent. for 56 miles. Up to 1891, inclines Nos. 1 and 2 were worked by Baldwin Consolidation engines and No. 3 by Baldwin Mogul engines, both having cylinders 16 inches × 20 inches, and the driving-wheels being 32 inches in the former case and 42 inches in the latter. It was found that greater power was required, and Baldwin compound engines had been obtained with cylinders 10 inches × 20 inches and 17 inches × 20 inches.

He considered that the advantage of a narrow gauge in regard to curves was greatly overrated. In Ceylon (5 feet 6 inches gauge) there were many curves of from 330 to 400 feet radius on 1 in 44, compensated. On the Mexican Railway (4 feet 8½ inches gauge) in 1881 and 1882 for many months the trains passed round a curve of 150 feet radius on 1 in 25 while a tunnel was being completed. On the Mexican National Railway a semicircular curve of 128 feet radius had been in use since 1882, thus giving the 3 feet gauge an advantage of 22 feet in radius only over the standard gauge. There were on the National several curves of 200 feet, but by gradual improvements the minimum radius was being raised to 280 feet. He thought that, if possible, a gradient of 1 in 40 should not be exceeded in mountain railways, and that when this could not be obtained, it would generally be advisable to pass at once to a gradient of 1 in 12 or steeper, using the rack.

By the courtesy of Mr. W. G. Raoul, he was enabled to append the following Table showing particulars of the tractive-power of the compound locomotives in use on the Mexican National Railway :—

Mr. Ferrar

Gradient.		Tractive-Power in Tons. Class Q. Baldwin Ten-Wheeled, Outside-Frame. Cylinders {10 inches × 20 inches. 17 „ × 20 „} Driving-Wheel Centres, 40 „ Weight of Engine 76,000 lbs. „ „ „ with Tender ready for Service 138,000 „	Tractive-Power in Tons. Class R. Baldwin Consolidation, Outside-Frame. Cylinders {10 inches × 20 inches. 17 „ × 20 „} Driving-Wheel Centres, 32 „ Weight of Engine 83,000 lbs. „ „ „ with Tender ready for Service 145,000 „
Feet per Mile.	Per cent.		
Level	Level	1,380	1,875
26·4	½	555	750
52·8	1	335	455
79 2	1½	235	315
105·2	2	175	235
132·0	2½	140	185
158·4	3	110	150
184·8	3½	95	125
211·2	4	85	115

NOTE.—The tenders when loaded weighed 62,000 lbs., or about 28 tons, which must be added in each case to obtain the actual tractive power of the engine.

Mr. Fraser. Mr. P. A. FRASER thought the Papers demonstrated the necessity of some general classification of all railways being adopted by engineers, based upon their carrying capacity and irrespective of gauge or traction system. Such terms as "light railways" and "mountain railways" would then obtain a distinct definition. In the case of the two lines described by Mr. Berg it was obvious they had nothing in common beyond the fact of ascending a mountain, and could no more be compared than the elevator of an hotel with the winding engines of a coal pit, except upon the basis of work done. The class to which a railway should belong might be determined by the number of tons which it was capable of transporting to a given distance or raising to a given height in a unit of time, and the term "speed-tons," made use of by Mr. Pownall, would aptly express this. To go a step further the efficiency of a railway might be arrived at by introducing a unit of cost, and such a formula as $E = \frac{S \times T}{C}$, where E was the efficiency, or amount of work done per unit of time and cost, S the speed in miles per hour, T the weight of net or paying load in tons, and C the cost of haulage per ton of net load, would afford a means of comparing all such lines and systems as those given in the Appendix to Mr. Borg's Paper. Where the system of traction used was similar, the degree of efficiency expressed would

be absolute; where dissimilar, the efficiency attained would be relative, a coefficient applicable to the system being found, just as in the case of girder-bridges or prime motors. Mr. Fraser.

It appeared from these and other Papers that engineers had abandoned adhesion-railways for gradients exceeding 1 in 30—and his own experience entirely agreed with this. Having had charge of the traffic of the Guaira Railway on a continuous gradient of 1 in 27, and of the Oroya Railway with its long stretches of 1 in 25, the danger, cost, and inconvenience of such gradients for ordinary locomotives were fully brought home to him. Apart from the loss of time through slipping in the ascent, and the liability to runaways from careless driving or deficient brakes in the descent, such lines presented their whole length to such dangers as landslips and washouts, against which a dense tropical vegetation was the only protection. In the Peruvian Andes the mountains were bare, and but for the fact that rain fell only at intervals of many years on the western slope of the Cordillera, the Oroya Railway could not have resisted the weather as it had hitherto done. From the fact of being in the tropics, avalanches were unknown, the snow line being above the height of the summit tunnel (15,648 feet). It had always been the regulation, however, for a pilot trolly to start down the mountain ahead of each train to inspect the track. The speed of trains, taken from the time tables, was 8·7 miles up and 11·3 miles down, per hour, but a trolly could cover the distance of 80 miles from Chicla to Lima in four hours. Accidents frequently happened to the trolly-men, and only the most rigorous discipline, and report by block-telegraph, could keep some of the more reckless engine-drivers under control. That no passengers had been killed in runaway trains upon the Oroya Railway since the line was opened in 1876 was due more to those who worked the line than to those who designed it. He had several times been in runaway trains that were pulled up by encountering sharp curves, and the feeling was not a pleasant one. Nothing but a sharp curve would stop such a train with all the wheels skidding on the rails.[1]

The Valley of the Rimac, up which the line forced its way by these heroic gradients and frequent switchbacks, really offered a

[1] The dangers alluded to were illustrated by an accident which occurred on the Interoceanic Railway of Mexico. A train was descending an incline at a high speed, and when entering a sharp curve part of it was thrown from the rails over the embankment, and dashed to pieces at the bottom of a precipice.—*The Times*, March 2, 1895.

Mr. Fraser. fair opportunity for much sounder engineering, and not only would the successive steps by which the river descended enable a line on the combined rack and adhesion system to be easily found, but the power available from a boisterous mountain torrent, ever running, and parallel to the railway for 70 miles, would, in the present day, not be neglected. Reference had been made by Mr. Pownall to the smoke nuisance in long tunnels on steep gradients. Even in the earlier tunnels through the Alps the question of ventilation had not received the attention it now did, and it was noteworthy that, in traversing the St. Gothard tunnel, the windows of the carriage could remain open without discomfort. This was not possible either in the Arlberg or the Mont Cenis tunnels, and was due to the difference between a gradient of 1 in 172, and those of 1 in 72 and 1 in 43.

The summit tunnel on the Oroya Railway stood at such a height above sea-level that to breathe even pure air was a painful exertion. Its length was ¾ mile, one-half of this being on a gradient of 1 in 27, preceded by an approach of 1 in 25 on a curve. The tunnel was for a single line only, and the use of coal-burning locomotives was most distressing to passengers. Fortunately the adoption of petroleum fuel on the Peruvian railways had got over this difficulty, and upon such a line as the Usui it would be thoroughly suitable, having regard not only to its perfect combustion and freedom from smoke, but to the economy of 50 per cent. in cost per mile over coal, and in weight of fuel carried. There could be no two opinions as to the advantage of petroleum fuel, where it could be obtained. That used in Peru was found on the Coast, and the adaptation of the locomotives and tenders to it was a simple matter.

Mr. Mallet. Mr. A. Mallet desired to comment on the criticisms of Mr. Berg (p. 11), with regard to the engine compounded on the "Mallet" system working on the St. Gothard inclines. First, as to the condensation in winter, the engine was put to work in 1891, and at first the steam-pipe connecting the two groups of cylinders, and acting as a receiver, was insufficiently protected, so that condensation ensued; but all that was necessary was to treat this pipe as the boilers, cylinders, and steam pipes (which in most Swiss railways were outside) were treated. There was nothing in this matter peculiar to the system of compounding; and on the Davos railway, at greater altitudes than were found on the St. Gothard, no such defect had been noted. The system had been considered complicated by Mr. Berg, but some complexity might be said to be inherent in the object sought after. At any rate it could be claimed that the

Mallet engine was less complicated than the Fairlie, there being but one bogie in place of two, and only one jointed steam-pipe, which carried steam at only 50 lbs. to 55 lbs. pressure. The Swiss lines employed at present four types of these engines, two on the normal gauge and two on the metre gauge.[1] He desired also to direct attention to an adhesion line recently opened (1893) from Yverdon to Ste. Croix in Switzerland, on which there were gradients of considerable length as steep as 1 in 22. This line was worked by similar engines to those above discussed. Although not of technical interest, the remarkable fact might be mentioned that, according to a stipulation made in the concession, at the express desire of the concessionnaire, no trains might travel on this line on Sundays. Mr. Mallet.

Mr. W. MARTINEAU directed attention to the Petropolis Railway, of which he had given some account in a previous discussion at the Institution.[2] In that case the use of the rack had been a perfect success, while it would have been most costly, if not impossible, to develop an adhesion line of 1 in 40. As an instance in the other direction, he would refer to a railway in the North of Spain on which he had reported. In this case the line, which was of metre gauge, had a steep section in the middle of its length, connecting a plateau above with a valley below. This section had eight or nine tunnels, with cuttings and banks on side-lying ground, the strata in some places sloping with the surface. The embankments were gradually sliding down into the valley and the upper sides of the cuttings also moving. This state of things should be foreseen and guarded against in mountain railways. The case referred to was a good one for introducing a steep gradient of about 1 mile in length, which he believed could have been made for half the money spent on the eight or nine miles of heavy and unsafe line actually built. Generally he would say that in any case where sections of ordinary railway are separated by a great difference of level, it was better to face the hill at once and adopt a steep gradient, though he would not advocate this on main through lines. Mr. Martineau.

Mr. J. R. MOSSE, although without experience in working either the Fell or the rack system, did not think that the approaches to the St. Gothard Tunnel would, if laid out at this date, have followed one of these systems rather than the present alignment with spiral tunnels, required to protect the railway from landslips Mr. Mosse.

[1] See Appendix to Mr. Collett's Paper, p. 31 *et seq.*, cols. 4, 10 and 11.
[2] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 152.

Mr. Mosse. and avalanches, and to give a gradient of 1 in 40. In fact, he did not believe that the existing traffic on these approaches could be carried on a very steep gradient by the Fell or rack system without increasing to a very inconvenient, if not dangerous, extent the number of trains.

Where the traffic was very light, and the trains consequently few, the Fell or rack system might suffice; but it would still be the duty of the engineer to provide for the future, and experience showed that, in general, the increase of traffic greatly exceeded previous anticipations. He thought that, unless there were an ample margin of engine-power, traffic was always carried disadvantageously, additional expense in working was incurred, and the delay involved was often accompanied with serious risks. He might state, as an instance, that on the Highland Railway in August and September last, between Perth and Forres, on a gradient said to be 1 in 40 or 1 in 50, the trains were so overloaded that they generally required two locomotives in front, with sometimes one also in the rear, and, notwithstanding this, they usually reached their destination one hour late. Some unusually powerful locomotives were said to have been since ordered for this service.

His eleven years' experience in the working of the Ceylon Government Railway, with gradients of 1 in 45, confirmed the opinion he had expressed[1] as to the Midland Railway of Mauritius, viz., that for long inclines the limit for working with advantage by adhesion was 1 in 40. On this gradient the trains ran with safety and comfort, but on steeper gradients they occasionally stopped, ran backward, or gave trouble. The adoption of pieces of comparatively level gradient on long and steep inclines was found to add greatly to the safety of descending trains.

Mr. Parsons. Mr. W. B. Parsons, of New York, had constructed, a few years ago, a system of railways in a very hilly portion of north-western Pennsylvania, for the transport of timber.[2] As these lines were only intended for a few years' service the utmost economy in construction was necessary, and the gauge had to be 4 feet 8½ inches in order to save the cost of transshipment. The main stem of the system had a gradient 3·64 miles long at a rate of 1 in 30, and was a succession of curves, many of which had a radius of 319·6 feet. In other parts of the system gradients up to 1 in 26 were frequently used, some of which were against the heavy

[1] Minutes of Proceedings Inst. C.E., vol. xxviii. p. 250.
[2] See Transactions American Soc. C.E., vol. xxv., 1891, p. 119.

traffic. Two classes of engines were used: one, the ordinary Mogul type with six coupled 4-feet driving wheels, a rigid wheel base of 10 feet, and a total weight of 35 tons, and the other being the Shay geared locomotive.[1] The chief advantages of the latter engine are the utilization of the whole weight of both engine and tender for adhesion, a flexible wheel-base and a high piston speed. On the railway above mentioned three Shay engines were used, varying in weight from 28 tons to 60 tons. The rails were 40 lbs. per yard, laid on soft-wood ties. Great care was taken with both alignment and level, so as to ensure uniform resistance. The value of this care had been proved when a runaway train, consisting of an engine and seven heavily loaded cars, passed safely round the sharp curves at a high speed and then left the rails, after passing on to the main line, at a point where there was no steep gradient or sharp curve, but where the same care in laying out the line had not been used. A railway in Utah, with which he was acquainted, had an incline 5 miles long with an average gradient of 1 in 12 and a maximum gradient of 1 in 9½ with curves of 50 feet radius. It was built to a gauge of about 30 inches, and was an adhesion line operated successfully by Shay engines, of which the heaviest weighed 20 tons and could haul up the incline 40 tons, besides its own weight. The line served silver mines and the bulk of the traffic was down hill. Mr. Parsons.

Mr. Riggenbach.

Mr. RIGGENBACH stated that he had, in conjunction with the Maschinenfabrik, of Esslingen, for ten years manufactured loco motives and other special apparatus for rack railways at the works at Esslingen. About forty such railways had been constructed, of which the most important was the Padang Railway in Sumatra. All the latest rack railways in Switzerland had been made with the Riggenbach rack, as, for instance, from Interlaken to Grindelwald and Lauterbrunnen, from Lauterbrunnen, by the Wengernalp, to Grindelwald, from Lucerne to Meiringen by the Brünig, and also the line from Monaco to La Turbie. He begged to submit to the Institution particulars of some of these lines.[2] He would like to call attention to the statement by Mr. Collett on p. 25 that the Riggenbach ladder-rack "is not so durable and effective as the Abt rack." This, he considered, was incorrect, and was quite at variance with the experience of the Rigi Railway, which was built as long ago as 1870 and showed no trace of wear yet.

---

[1] For description, see p. 129; also Transactions American Soc. C.E., vol. xxv, 1891, p. 119.

[2] See Appendix to Mr. Collett's Paper, p. 31 *et seq.*, cols. 21, 27 and 33.

Mr. Rinecker. Mr. F. Rinecker, of Würzburg, commented on Mr. Collett's observation (p. 26) to the effect that the speed on rack railways was at present somewhat low, pointing out that the introduction of the rack in no way altered the principle of the time rate of work done being measured by force × velocity. The object of the rack was to enable the factor "force" in this expression to be increased without increasing the weight of the motor, by removing the limit to the "force" (*i e.*, tractive-force) imposed by adhesion. But if this object were attained and the weight of the motor not increased, then the power developed was the same as before, being mainly dependent on heating-surface. If now one of the factors of the expression force × velocity were increased, the other must be diminished to leave the product unaltered. The velocity must necessarily be reduced, therefore, as the gradient became steeper, unless either the motor was made stronger, and consequently heavier, or the train-load made lighter. Further, he considered the measurement of speed of trains by horizontal distance traversed to be fallacious when applied to mountain railways; the vertical distance traversed would be a better measurement of speed. With a velocity of 7 miles per hour on 1 in 16, the speed of vertical rising would be the same as with 17½ miles per hour on 1 in 40, being at the rate of 2,310 feet rise per hour. He thought also that the measurement of coal-consumption in lbs. per train-mile was misleading when applied to mountain railways, the mileage travelled being in these cases no measure of the work done by the locomotive. If, instead of this, a standard of 1,000 foot-tons (*i.e.*, train-weight × vertical height) or some similar standard were used, the comparison would be of some value, and the advantage of the rack in such cases would appear. The losses due to friction were less as the gradient was steeper because of the shorter length of line, and a further saving arose from the motor being lighter and thus giving a smaller total weight to be lifted in proportion to the train-load proper.

Proceeding to Mr. Pownall's Paper, he desired to call in question the statement on p. 49, that "in consequence of the small heating-surface provided, the locomotives proved unable to take up the inclines more than two-thirds of what was expected." This statement reflected seriously on the inventor and designer of the engines, and nothing was to be found in the Paper by way of justification for it. The leading dimensions of the engines had been most carefully calculated, and submitted to the consulting engineer of the railway in England. They had been sent to Japan in such time that any desired alteration could have been made before the con-

struction of the engines was proceeded with. No error had been observed by any of the persons who had examined the calculations and drawings, for the simple reason that none existed. The design was made on the same principles as had been followed in other cases, where all anticipations had been realized. If it were true that the expected duty had not been obtained from the engines (and no official complaint on the subject had ever been made), he would attribute such a result to the inexperience of the Japanese drivers employed. It had been pointed out to the Japanese authorities that a combination locomotive required a special knowledge to handle it properly, and it was proposed to send out a mechanic to erect the engines and to instruct the drivers as to the working of them. The Japanese authorities would not listen to this proposal, and the result was that, as he believed, very grave mistakes had been made in handling the engines, and permanent injury had been done to them. He believed that the figures in Mr. Pownall's hands showed the heating-surface to be equal to developing 294 HP., which would be more than sufficient for taking a train of 100 tons up 1 in 15 at a speed of 5 miles per hour. Mr. Rinecker.

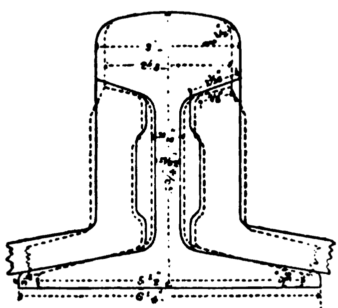
He wished also to call in question the propriety of using "speed-tons," as defined by Mr. Pownall, for comparing the merits of an adhesion with those of a rack railway. The speed was in miles of horizontal distance, and the main part of the mechanical work was done in lifting the load vertically. The vertical velocity of the train would form a much better element than the horizontal velocity in such a comparison. Taking Mr. Pownall's figures for the Hartz and Eisenerz inclines, and for the Gotemba respectively, in the former case a lift of 2,257 feet was obtained in one hour, whereas in the latter the lift was only 1,557 feet. The train-weights being 118 tons and 136 tons respectively, the figures obtained by multiplication would be 266,326 foot-tons per hour for the Hartz and Eisenerz, and 211,752 for the Gotemba.

Mr. Pownall's statement that the adhesion incline in this case would take double the traffic of the rack incline was, he thought, misleading. A true comparison would show the traffic capacity to be much the same, if the locomotives were of the same power in the two cases. The main advantage of the rack system, combined with adhesion, would always lie in the saving in cost of construction, and here the railway forming the subject of the Paper would not appear to be a favourable example of the use of the rack. If an adhesion line with no heavy works could, as Mr. Pownall said, have been built for almost the same cost as the steeper rack incline

Mr. Rinecker. it would probably have been preferable to build it as an adhesion line, with perhaps an occasional rack section of not too steep a gradient, in order to enable the heavier trains to be worked on it. The almost continuous tunnel of the line, as built, must be objectionable, and should not be credited to the Abt system.

Mr. Sandberg. Mr. C. P. SANDBERG, in reference to the remarks on the permanent-way of the St. Gothard Railway in Mr. Berg's Paper, submitted a drawing of the rail-joint used with his first 100-lbs. Goliath rail,[1] and also a drawing comparing the section of that rail with that of a new 100-lbs. rail designed by him in 1894, *Fig. 1.* The latter had not yet been tried, but a similar design of 50 lbs. weight had been made and found preferable to the old section. He had lately designed and inspected a 110-lbs. flange-rail, now being laid in place of an 87-lbs. rail, in a tunnel on an English railway, with a view to increasing the life of the rail by 50 per cent. and reducing the cost of maintenance. This rail was to be laid direct on the sleeper, and had a flange-width of $6\frac{1}{2}$ inches. In tunnels, owing to the moist and sulphurous atmosphere, a rail sometimes would lose 2 lbs. per yard per year, and this rapid corrosion should always be considered in designing a rail-section for tunnels.

Fig. 1.



Rail of 1894—Full lines.
,, 1886—Dotted lines.

	1894.	1886.	
Area of head . .	46	43	per cent.
,, web . .	17	22	,,
,, flange .	37	35	,,
	100	100	

He called attention to the relative weight of the engines and the rails on the St. Gothard line. The general principle in England was to have heavier rails, as compared to the engine-weights, than were used on the Continent. This might be necessitated by the higher speeds in England; but he thought the English policy was undoubtedly the right one, from the point of view of economy in maintenance, especially with rails at their present price. The increase in weight of rails used on the St. Gothard Railway, described by Mr. Berg on p. 6 of his Paper, was small as compared with the increase that had taken place in England in the same time, since 110 lbs. had

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 365, Sandberg on "Rail Joints and Steel Rails."

already been reached with, say, rolling stock half as heavy as that of the St. Gothard. He thought that this progressive increase would still continue for the sake of safety, comfort and economy in travelling, and that it would be well for continental railways to follow the example. Mr. Sandberg.

Mr. A. Schucan, of Davos-Platz, in sending printed information with regard to the Landquart-Davos Railway and a plan of snow-defences,[1] explained that in the Klus valley it was necessary to protect the line against stones that might descend from a height of 2,000 feet, as well as against avalanches. A combination of terraces retained by dry-stone walls, and fences of timber and iron rails was employed, and had answered very well. The defences had suffered injury, but the line itself had entirely escaped. Trees had been planted between the line and the terraces. It was intended to gradually make the system of defence more complete. Mr. Schucan.

The general protection of the line against snow was effected by posts standing 5 feet out of the ground, about a foot apart, in rows about 16 feet from each other. If the posts were not placed near together the light snow drove between them. The removal of snow from the line was found a serious item of cost. The total snowfall in 1890 was 15 feet; in 1891 the same; and in 1892 nearly 14 feet. The greatest depth of fallen snow was in 1890, 2 feet 10 inches; in 1891, 4 feet; in 1892, 8 feet 8 inches; in 1893, 5 feet 6 inches. The cost of removal was in the same four years £136, £254, £1,184 and £875 respectively. Fortunately very little drifting occurred. The methods used to remove the snow were, (1) small snow-ploughs attached to the engines; (2) a larger plough on separate wheels; and (3) manual labour. The traffic had only once been interrupted by snow, when, in 1892, an avalanche descended at a place where such an accident had not been apprehended.

The heavier compound engines (Mallet system) had been ordered in consequence of the rapid increase of goods traffic which made it necessary very frequently to put an assistant engine on the trains. There had been a considerable saving in fuel and wages from the use of these engines. Thus, in 1891, the traffic expenses were 20·5*d.* per train-mile; while, in 1893, they were 15·3*d.* per train-mile. The coal consumption was, in 1891, 3¾ lbs. per axle per mile, and in 1893, 3·23 lbs. The repair of the Mallet engines was not more

[1] See Appendix to Correspondence, p. 150; also Appendix to Mr. Collett's Paper, p. 37, col. 10.

Mr. Schucan. costly in proportion to their tractive-power than that of the lighter engines.

It had always been supposed, previously to the construction of the St. Gothard line, that the coefficient of adhesion in the higher Alpine regions was less favourable than at lower elevations, and for this reason the gradients in the higher parts of the St. Gothard line were reduced. The experience of the Davos Railway entirely contradicted this view. The adhesion was lowest in the tracts exposed to fog. The difference was most marked in winter, for the frost was constant in the higher regions and the rails dry, while, lower down, the fog and the frequent alternations of frost and thaw were embarrassing. In the mountains a coefficient of one-sixth could nearly always be reckoned on, while in the valleys often not more than one-eighth to one-seventh would be obtained.

The Landquart-Davos line was sufficiently successful to enable an extension to be made from Landquart to Chur and Thusis, which was now under construction. This line would be 25 miles long, and was expected to be ready for use by July, 1896. It was intended for local traffic, and also to obtain the road traffic now using the Oberalp, Lukmanier, Bernardine, Splügen, Julier and Albula passes. The steepest gradient was 1 in 40, sharpest curve 328 feet radius; estimated cost, inclusive of equipment and financing, £240,000, or £9,600 per mile. It was hoped in future to carry the line into the Engadine valley, either from Davos over the Scaletta pass, or from Thusis over the Albula.

Mr. Trevithick. Mr. F. H. Trevithick remarked that he had carried out tests with the locomotives working on the Usui Railway; and in February, 1893, had drawn up a joint report with Mr. Pownall, for the director of railways, on the Usui Railway, and on the working of the four original Abt engines. The frames and other working parts were too lightly constructed to stand the heavy strains when the four cylinders of the combination-engine were working. The fire-grate area and heating-surface were too small to supply steam when working a heavy train up 2½ miles of 1 in 15. Japanese coal was used, which made steam well, although soft and smoky; the consumption was about 300 lbs. per mile with a train of 50 tons.

The ventilation of the tunnels was a very serious question, there being twenty-six tunnels, 2·76 miles, in a distance of a little over 4 miles. The atmospheric conditions in these tunnels were very trying to those on the engine, the immediate cause being the intense heat of the air, caused by the great volume of steam from the four cylinders working together, and almost without expansion, and added to other products of combustion

discharged from the chimney. The feeling on the uncovered parts of the body was not far short of acute pain, and to this was added the necessity of breathing the heated atmosphere. The conditions varied with wind and weather; the same tunnel would be passed through on the same day, one time without discomfort, the next with great discomfort. The train on entering the tunnel acted as a plunger or piston, driving the air before it; the exhaust steam was discharged against the tunnel roof, and enveloped the engine in smoke; the vacuum caused by the train entering the tunnel was filled with the air following the train into the tunnel, this volume of moving air being increased as the train proceeded and being also aided by the incline of 1 in 15, and by the condensation of the steam from the engine. Eventually, this volume of air drove the smoke beyond the engine and the carriages. A canvas curtain was now pulled across the mouth directly the train had entered. The vacuum was then filled with air from the front of the train, thereby keeping the smoke behind the engine. This arrangement had acted in a more satisfactory manner than any other appliance which had been tried. The speed with six carriages (50 tons) was about 5 miles per hour. Mr. Trevithick.

Mr. F. J. Waring, C.M.G., with reference first to Mr. Berg's Paper, stated that he considered, in treacherous loose formations not liable to slip in large masses but having a tendency to crumble away, the best procedure was to widen the formation breadth of the cutting, and thus to allow room for any material which might come down to fall without interrupting the traffic. It was often, in steep side-long ground, impracticable to flatten slopes beyond a certain angle on account of the great height to which they would extend, and even if this were practicable, it would be often objectionable, as exposing a greater surface to the disintegrating action of the weather. It would, he thought, be interesting if Mr. Berg were to state what was the radius of the sharpest curve on the approaches to the St. Gothard tunnel, and whether it was used on the steepest gradient, or, if not, what was the limit of curve used on that gradient. He could hardly think that Mr. Berg meant that a maximum speed of 35 miles an hour was attained on the St. Gothard inclines of 1 in 37 and 1 in 40, and it would be well to know what was the speed on those gradients. Mr. Waring.

His own practice of late years on mountain railways in Ceylon, where the super-elevation of the outer rail was sometimes as much as 6 inches, had been to give the full amount at the point of commencement of the curve and to run it out in a distance of 33 feet on the straight. This was, he knew, rather sharp, but

Mr. Waring. where the length of straight between reverse curves was compulsory, sometimes as short as one chain only, there seemed to him to be no alternative. He hardly thought that the practical value of transition curves, such as those referred to by Mr. Berg, was, especially if the speed were low, commensurate with the trouble involved in setting them out. The batter of the retaining walls, shown in *Fig. 4*, was not given, and he hoped Mr. Berg could supply it; by scaling it seemed to be about 1 in $2\frac{3}{4}$. He was much struck with the very high cost of the cable railways appearing in Mr. Berg's Appendix, but he presumed that, as he believed they had been for the most part made for very special objects, ordinary commercial considerations were hardly applicable to them.

With reference to the Appendix to Mr. Collett's Paper, he would only remark that the Kadugannawa incline of the Ceylon Government Railway had been to a large extent dwarfed by the inclines on the extension of the railway to Nanu Oya, a description of which, with the engines and rolling stock in use thereon, had been given to the Institution by Mr. Mosse and himself,[1] as well as by the inclines on the further extension of the line to Haputale and Bandarawela which had only lately been finished. He had read Mr. Pownall's Paper with much interest, and feared a serious mistake had been made, the gravity of which the growth of traffic that always follows on the construction of a railway would in a few years render abundantly manifest. The line over the Usui Pass was a trunk-line connecting the eastern and western railway systems of Japan, and it seemed to him that the introduction into the centre of any trunk-railway system, of a short section of line requiring special appliances for working it, was a question demanding the gravest consideration and one only to be adopted in very extreme cases. It was apparent that even at present the traffic over the Pass, the summit of which from the west coast had been already reached at Karuisawa by an ordinary locomotive line with gradients of 1 in 40, was considerable. There was only therefore the descent on the east side to Yokogawa to be considered. It was stated that a route $15\frac{1}{4}$ miles in length, with a maximum gradient of 1 in 40 and with curves of ten chains radius, and an aggregate length of tunnels of $4\frac{3}{4}$ miles, could be obtained at a cost of £300,000. For such a line he thought there would be no difficulty in designing an engine without having any excessive weights on the coupled wheels which would take up trains weighing say 140 tons at about 12 miles per hour, and the journey would thus

[1] Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 96, and vol. xc. p. 319.

occupy about one hour and twenty minutes. In the place of this, a line 7 miles in length, with gradients of 1 in 15, having 2⅜ miles of tunnel, had been built at a cost of £298,669, or for practically the same sum as the alternative line was estimated to cost. On this line the rack locomotive, with an average load of 11·15 tons per axle on each of the three coupled driving-wheels, took up, ordinarily, loads of from 60 to 70 tons at 4·7 miles per hour; about one hour and a half was thus occupied in ascending the incline. Mr. Waring.

The adoption of the rack and adhesion system therefore, in this instance, had not been attended with any saving of time in the journey nor of money in the cost of construction, while the weight of the train had been reduced to about one-half of what it might have been had the ordinary locomotive line been adopted. He ventured to hope that Mr. Pownall would be able to add some statistics as to the cost of working the Usui Mountain Railway, and be able to compare them with similar statistics relating to the cost of working the incline of 1 in 40 by which the Usui Pass was approached on the western side, and this would, he considered, add much to the value of his already interesting and valuable Paper.

Mr. W. J. Weightman observed that the Stanzerhorn incline, described by Mr. Berg, did not appear to differ very materially in details from its predecessors; the division of the whole ascent into sections could hardly be claimed as a novelty, as this had already been done both on the São Paulo and on the Khojak inclines. The arrangement for crossing the cars in the centre was similar to that used on the Bürgenstock incline, and was a modification of the plan first adopted at the Giessbach, but, on the latter, instead of the outer wheels having double flanges, and the inner being without, the wheels of one car had outside flanges, and of the other had inside flanges. Both these arrangements were open to the objection that the wheels of both cars had to pass over the rope at the upper crossing, and should the rope omit to drop into the gap in the rails prepared for it (and this had been known to happen) it would be liable to be damaged. Mr. Weightman.

The brake arrangement was ingenious, and was somewhat similar to that adopted many years ago on the Croix-Rousse incline at Lyons, but had the advantage of being able to be applied by hand or foot, whereas that at Lyons only came into action when the rope broke. He did not, however, think that a brake of this description was as reliable as a rack-brake. If the car once attained any considerable velocity the friction-clutch would, in all probability, not work. With a rack-brake the danger of the pinion mounting the rack, which Mr. Berg was afraid of, was

Mr. Weightman. guarded against in a very simple manner on the Chiaia (Naples) incline by means of an inverted T-shaped bar suspended from each car, and running between the two rack-bars.

The weight of a fully loaded car on the Stanzerhorn incline was not given, but would appear to be not more than 6 tons. Were it more than this it was doubtful if the method of winding the cable would provide sufficient friction. All the older rope inclines on the Continent, such as the two well-known lines at Lyons, and that at Lausanne, followed the old English colliery practice of having large drums on which the whole cable was coiled; two cables were used, one being uncoiled as the other was coiled, and *vice versâ*. The more modern inclines used, as in this case, a single cable, passing round two or more pulleys, each with several grooves, to obtain the necessary friction. The use of clip-drums, so common in England, did not appear to have extended to the Continent, probably owing to the erroneous idea that they injured the rope. He had carefully examined ropes which had worked for more than a year over a Fowler clip-pulley, and could find no perceptible flattening.

To the particulars in Mr. Collett's Tables might be added that engines in use on the Great Indian Peninsula Railway[1] hauled trains of 250 tons up the Bhore and Thul Ghats (1 in 37); this gave 4·4 tons per ton of engine. This method, however, of comparing the efficiencies of different engines on different lines was not a very satisfactory one, as it took no account of the gradient. He had adopted instead the following method:—Knowing the adhesive weight of the engine, a calculation was made of the load which theoretically it should take on the gradient with a coefficient of $\frac{1}{7}$; this was called 100. According as the engine in actual practice took more or less than this amount, the number 100 was proportionately increased or decreased, and this figure was called the efficiency of that particular engine on that particular line. For example, the efficiencies of the engines in columns 1, 6, 16, and 22 were respectively 96, 84, 118, 133, and that of the rack engine in column 12 was 262, and of the Fell engine in column 17 was 260.

In his description of the Usui Railway, Mr. Pownall had explained that all bridges were built with brick arches because it was feared that girders on a gradient of 1 in 15 would be forced downhill; it would be interesting to have the opinion of other

[1] Similar to those mentioned in the Appendix to Mr. Collett's Paper, p. 38, col. 16, *ante*, and also described in Minutes of Proceedings Inst. C.E., vol. cxii., p. 311.

engineers on this point. On the Nilgiri rack-railway, which he (Mr. Weightman) was now engaged in constructing, there were altogether eighty spans of girders (20 feet, 40 feet, and 60 feet) being built on a gradient of 1 in 12½, and he thought there was no occasion to anticipate trouble with them. On single-span bridges a stout angle-bar was riveted to the lower boom and butted against the masonry of the lower abutment; the lower ends of the girders also were built in solid, the expansion taking place upwards. Where the bridge consisted of more than one span, a heavy cast-iron bed-plate with its top-surface parallel to the gradient was securely bolted on to each pier. Mr. Weightman.

The opinion was expressed in Mr. Pownall's Paper (p. 50) that under certain circumstances 1 in 15 was too steep for a rack railway, and it was stated that the Austrian Government had fixed 1 in 22½ as the limit. He was not aware of any rack railway which had been constructed on the Continent with a gradient so flat as this. The flattest rack railway ever made was the temporary 1 in 25 line in the Bolan Pass, and notwithstanding the marvellous feat of a single Abt engine of 51 tons taking a 304-ton train up this incline, the opinion generally appeared to have been that such a gradient was too flat a one to bring out to the full the advantages of the rack system. The unsatisfactory working of the engines on the Montserrat Railway was, he thought, due to the pinions being fixed on the carrying axles. This system was now, he believed, very generally condemned; as the tires of the carrying wheels wore, the pitch line of the pinion was lowered with respect to the rack and the gearing obviously became imperfect. It might be as well to point out that the curves of the rack portion of the Hartz were of 918 feet radius and not 656 feet as shown in column 12, p. 37.

He could not agree with Mr. Pownall's method of expressing traffic-capacity in terms of speed-tons. The factor which most determined traffic-capacity was the distance between block- or crossing-stations. Mr. Pownall's calculation was based on the assumption that these distances were equal on the two lines being compared, but as a matter of fact they were not, being very much less on the Hartz and Eisenerz Railways than they were on the Gotemba. If an engineer were submitting alternative schemes for a rack and an adhesion line, the speed on the one being less than on the other, he would naturally place the crossing stations closer on the former than on the latter, so as to make the carrying-capacity of the two lines equal. Reference had been made by Mr. Collett to the cheapness of construction of the Montserrat Railway, but he did not state what the cost actually was. It

Mr. Weightman. would be interesting if these figures could be given. The question of cost was perhaps the most important consideration in determining which of several alternative lines of different gradients and systems was most suitable. Mr. Weightman had compiled from various sources the cost per mile of the principal mountain railways in the world, the most expensive on record appearing to be the Semmering Railway in the Tyrolese Alps, which cost £98,000 per mile, while the cheapest were lumber railways in Pennsylvania, which cost about £2,000 per mile. The figures appeared to show that a rack railway did not cost more, mile for mile, than an adhesion line passing through similar country, while the saving in length in the former was usually very great. It was, however, dangerous to attempt to draw any inferences from this, or to try to lay down any hard and fast rules. Every mountain railway was a problem in itself and required to be solved independently as such.

Mr. Collett. Mr. Collett, in reply to the correspondence, considered the result of the trial on the incline between Madison and Indianapolis mentioned by Mr. Becker to be highly interesting. The load hauled by this adhesion engine, 2·72 per ton of engine weight, over $1\frac{1}{3}$ mile of incline averaging 1 in 17 gradient, was an extraordinary performance; but, as was well known, these trial trips could not be used as a gauge of the regular adhesion working of the incline, and must be taken for purposes of comparison with the exceptional loads of the Table, appearing therefore to correspond with the Hartz Railway with a similar grade. It was a pity Mr. Becker did not mention the ordinary load hauled in every-day practice. As regards the greater economy claimed for these adhesion engines, it must be remembered that the rack engines and appliances in use from 1847 to 1868 could not be compared, as regards economical working, with the rack appliances used at the present day. The situation as regards climate must be very good for adhesion work, when Mr. Becker mentioned that "No want of adhesion had ever been experienced in any weather," and could not be taken as a guide for other inclines not so favourably situated. As regarded mountain survey work mentioned by Mr. Bell, Mr. Collett had also often been surprised, when working in mountainous parts of Brazil, to find how 1 in 50 gradients and five- or six-chain curves sometimes enabled a fairly economical line to be laid out through narrow valleys with precipitous sides, which on first inspection seemed to offer insuperable difficulties to the passage of a railway without expensive work. His illustration of the 40-ton engine which could not haul four empty flat cars up 1 in 22 in

foggy weather, strikingly illustrated the advantage of a special system in similar climates. In regard to wear, Mr. Collett did not refer specially to the wear of the teeth, but to the general durability of a ladder-rack consisting of so many parts. It had been stated by Mr. Rinecker that the speed measurement by horizontal distance traversed was fallacious when applied to mountain railways. Mr. Collett agreed with him as regarded very steep inclines. The method of comparison of engines proposed by Mr. Weightman was interesting, but did not seem to Mr. Collett to give a fair comparison as between adhesion-engines and light pure-rack engines; moreover it began with the assumption that rack-engines had only one-seventh available for adhesion, which was incorrect. As regards the pinions being fixed on the axles, this was not found to be a cause of trouble on the Montserrat engines; as on most inclines, a great deal depended on the driver. He agreed with the remarks of Mr. Martineau as to facing a hill at once, especially where railways were required to develop a sparsely inhabited country like Brazil. Mr. Collett.

Mr. C. A. W. Pownall, in reply to the discussion, considered, after studying the results obtained on the heavy adhesion inclines at Gotemba and the rack-adhesion line at Usui, that no such study could be complete without including the factor of speed. The introduction of this factor, alluded to in the Paper, had been fully endorsed by Mr. Burnett, who had said that it was impossible without it to make any useful comparison. Indeed, figures might otherwise become entirely misleading; for example, the cost of working at the Hartz rack-and-adhesion line had been compared[1] with that at the Semmering adhesion inclines to the advantage of the former by 23·4 per cent. But the speed had not been mentioned, and was, by the schedule, over 22 miles an hour at the Semmering, but only one-third as much at the Hartz. Such saving in cost would therefore be dearly bought where the traffic was large, on account of the loss of power to pass trains over the line. With regard to the remarks of Mr. Carruthers as to the expenditure of the same power by two engines, one with and one without a rack, he thought it was merely a matter of fact that the effective power was not the HP. an engine could theoretically develop but that which it could practically use. So, on the Kicking-Horse Pass the 52-ton engines of the Canadian Pacific Railway were doing work equal to 250 HP., while the Hartz engines of 55 tons—almost the Mr. Pownall.

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 135.

Mr. Pownall. same weight, and weight and power went together—were producing and using 486 HP., because one-half their work was done on the rack independently of the factor of adhesion. Mr. Carruthers appeared to have supposed that at the Usui there had been some possibility of running the railway on the level for 10 miles west of Yokogawa, and then "springing the whole height" to the summit. But as this was but 4½ miles west of Yokogawa, as the crow flew, such a question could never have arisen. The issue had lain between increasing that distance by development for an adhesion line, or accepting it nearly as found by starting a 1 in 15 incline a short distance from Yokogawa, as shown in the section (*Fig. 1*, p. 45) of the line as made. The Government returns showed that in Japan the cost of maintenance was £150 per annum per mile of railway; for 10 miles therefore it would be £1,500, or ½ per cent. on the capital expended at the Usui.[1] Weighed against the possibility of more than doubling both the present loads and speeds over the line by the addition of those 10 miles, the reduction of ½ per cent. from interest for their maintenance would have been quite immaterial. The essential difference between the broken gradients over undulating ground at the Hartz and the long continuous incline at the Usui had been at once grasped by Mr. Holtham, whose opinion as to a Japanese problem rested on a thorough knowledge of the country. He suggested that for the latter line a pure rack engine, instead of one with rack and adhesion, might have been preferable. This point had been considered in 1890, when the 1 in 15 incline had been proposed; but the rack-and-adhesion system had been adopted because on such a gradient the engine could draw a weight equal to itself by adhesion, leaving only the tractive-effort for the difference between train- and engine-weights to come on the teeth of the rack. In this plan, under present conditions, the strain and the wear and tear on that vital part had been reduced fully one-half. Of course that might be met, as on the Delagoa Bay Railway, so appositely cited by Mr. Sawyer, by helping the train up with a rack locomotive as auxiliary to the adhesion engine; but then on the return trip the latter was a superfluity in the descent, while on the ascent the weight of the two together must exceed that of one combination engine. The diminution of work thrown on the rack-bars by the use of the combination instead of the pure-rack engine had been referred to by Mr. Worthington, who, having visited the Usui

[1] On the St. Gothard Railway the cost of maintenance was less than 1 per cent. of capital.—*Engineering*, January 11, 1895, p. 42.

line, had also been able to testify to the difficulty there experienced with the ventilation. Mr. Pownall.

For the performance of the original engines, 294 HP. had been stated by Mr. Fairholme, instead of the 200 HP. given in the Paper. The former figure would have been in accordance with the power that had been expected to be developed, but the usual formula applied to the loads and speeds as given would show that the latter represented the work available. Indeed, the inventor of this system laid it down as a rule[1] that a well-designed combination engine would develop 3 HP. per square metre of heating-surface at a speed of 8 kilometres per hour, and as these engines had 75 square metres of heating-surface, their ideal performance would be $75 \times 3 = 225$ HP.; so that the 200 HP. which was being obtained by the Japanese drivers was not much below the maximum, although stress had been laid on want of skill and experience on the part of these men. In the new engines to be shortly supplied by Messrs. Beyer, Peacock & Co., there was to be a total heating-surface of 118 square metres. The statement in the Paper that 1 in 15 was regarded as too steep for the rack, should have been qualified by its limitation to heavy lines, but it was only with such lines that the Paper dealt, and no allusion was intended in it to light-tourist traffic. The keynote to this discussion had been struck nearly fifteen years ago by Dr. Pole, who had said[2] of the Rigi line that "the rack principle there used ought to be considered as an exceptional thing, only to be applied in extreme cases where no other system was possible." Such extreme cases occurred more and more frequently, and when they arose he believed that the Abt rack, properly applied, would be found a valuable auxiliary.

In reply to the correspondence, Mr. Pownall desired to add that the figure \$2,000,000 (£300,000), for the alternative proposal of a development line at the Usui, was, as he had expressed it, only an approximate estimate, and that it might have been exceeded in the execution of the works by that method if it had been adopted. There would, however, have been no great margin for such excess, for the cost of the tunnels, which formed the heaviest item, had been stated in the estimate of 1889 at \$150 a yard, and so amounted to nearly \$1,200,000, while the cost of tunnelling for the rack line in an adjoining valley was \$155 a yard, or only \$5 more. A

[1] Wochenschrift des österreichischen Ingenieur- und Architekten-Vereins, Vienna, 1888, p. 108.

[2] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 92.

Mr. Pownall. further confirmation of the estimate of $2,000,000 was that it amounted to $145,666 per mile of railway, while $148,146 per mile was the figure separately and previously arrived at by a Japanese engineer, Mr. Minami, for a railway over the same valleys. Special features in each case being allowed for, the two estimates were practically identical.

15 January, 1895.

SIR BENJAMIN BAKER, K.C.M.G., Vice-President, in the Chair.

The discussion on the Papers on "Mountain Railways" occupied the evening.

22 January, 1895.

JOHN WOLFE BARRY, C.B., Vice-President, in the Chair.

The discussion on the Papers on "Mountain Railways" was continued and concluded.

APPENDIX TO CORRESPONDENCE.

APPENDIX TO CORRESPONDENCE.

List of Documents referring to Mountain Railways presented to the Institution by various Correspondents.

[The name of the donor is given in brackets in each case.]

"Chemin de fer funiculaire Territet-Glion," by A. Vautier, 1885.

"Die Drahtseilbahn Territet-Glion," by Emil Strub, Aarau, 1888. Two plans entitled "Disposition des freins" and "Modification du profil en long" respectively. [Chemin de fer de Territet-Montreux-Glion.]

"Locomotives operating by Total Adhesion on Curves of Small Radius," by A. Mallet, Paris. Reprinted from Transactions of American Society of Mechanical Engineers, vol. xiv. (Chicago Meeting, July, 1893). [A. Mallet.]

"Chemins de fer à fortes pentes," by N. Riggenbach, 4th edition, 1883.

"Chemins de fer à fortes pentes et à crémaillère," by N. Riggenbach; 5th edition, 1889.

Nine longitudinal sections of rack railways, four drawings of permanent way (Riggenbach system), nine photographs, and eleven blue prints of rack-driving locomotives made at the Esslingen Works. [Maschinenfabrik Esslingen, Würtemberg.]

"Die Vitznau-Rigibahn Locomotiven" and "Oberbau der Vitznau-Rigibahn," by E. Strub. Reprinted from the "Schweizerische Bauzeitung," Bd. XVI. Nos. 21 and 22, and Bd. XVII. No. 12. [— Fellmann.]

"Schweizerische Bauzeitung," Bd. XVI. Nos. 9, 10 and 11 (with description and drawings of Landquart-Davos Railway by — Johner, Zurich).

General plan of defences against stones and snow in the Klus Valley.

Report and accounts of the Landquart-Davos Railway for the year 1893.

Regulations of the Landquart-Davos Railway (containing, on pp. 15 and 16, particulars of the locomotives, wagons and carriages). [Landquart-Davos Railway Company.]

Sheet of diagrams entitled "The Abt System at Oertelsbruch." [Roman Abt.]

"The Incline Plane Railroad at Madison, Ind.: its History and Operation," By M. J. Becker, M. Am. Soc. C.E. Extracted from the Transactions of the American Society of Civil Engineers, vol. vii., March, 1878.

Three photographs of locomotives used on the Incline Plane Railroad at Madison, Ind. [M. J. Becker.]

"Mountain Railroad Construction," by William Barclay Parsons, M. Am. Soc. C.E. Extracted from the Transactions of the American Society of Civil Engineers, vol. xxv., July, 1891, p. 119. [W. B. Parsons.]

Photograph and blue print of Shay geared locomotive.

Plan and diagram of gradients of the Tiadaghton and Fahnastalk Railroad, Pennsylvania, U.S.A. [Foster Crowell.]

Drawing of rack-and-adhesion engine used on Brünig Railway.

Sheet of particulars with regard to the Brünig Railway. [Jura-Simplon Railway.]

"Eine Strassenbahn mit Zahnstrecken (St. Gallen-Gais)," by Professor A. Goering, Berlin. [Appenzell Street Railway.]

29 January, 1895.

JOHN WOLFE BARRY, C.B., Vice-President,
in the Chair.

(*Paper No. 2769.*)

(*Abridged.*)

"Boiler Explosions."

By WILLIAM HENRY FOWLER, Wh.Sc., Assoc. M. Inst. C.E.

IT is proposed to deal in this Paper with the subject of boiler explosions in its broad engineering aspect; and before entering upon the consideration of it, some of the old theories of boiler explosions may well be recapitulated, although it is not now worth while to refute them. The theories alluded to are those of (1) deferred ebullition; (2) dissociation and sudden recombination of the oxygen and hydrogen of the water; and (3) spheroidal condition of water in contact with overheated plates, and sudden excessive increase of pressure when water is admitted.[1]

The importance of clearly understanding the causes of boiler explosions is evident when the destructive effects of which they are often the origin are considered. As it is not universally understood that it is not so much the steam as the hot water which is the destructive agent, a brief enquiry as to where the energy is stored is an important preliminary to the general study of the question. When it became recognised that a boiler-shell was normally in a state of high tension, and that when once a rupture was produced by the action of the static stresses on a locally weak spot, the stored-up energy was capable not only of enlarging it into a complicated series of rents extending through the sound portions of the structure, but of producing all the other destructive effects observed in such cases, the investigation of these disasters was

---

[1] Report of the Chief Engineer of the Manchester Steam Users Association, January and February, 1867; also Report on a Series of Red-hot Furnace-crown Experiments, by the same Author, 1889.

placed on a satisfactory basis and a long step was taken towards their elucidation. The amount of energy stored in the hot water and the steam of a boiler, and capable of being expended in the event of explosion, is readily calculable by well-known thermo-dynamic methods. The question was investigated concurrently by Airy [1] and Rankine [2] in 1863. Into the details of the reasoning it is scarcely necessary to enter, since they can be found in most treatises on thermo-dynamics. It is sufficient for the Author's present purpose to give the numerical results contained in Table I.[3]

TABLE I.

Absolute Pressure.	Initial Temperature.	Total Energy Liberated on Reduction of the Pressure to Atmospheric Pressure, and of the Temperature to 212° F.	
		By 1 lb. of Water.	By 1 lb. of Steam.
Lbs. per Sq. Inch.	° F.	Foot-pounds.	Foot-pounds.
25	240	440	29,596
50	281	2,550	68,164
75	307	4,816	90,739
100	327	6,885	106,673
150	358	10,536	129,004
200	381	14,153	145,121
250	401	17,314	157,830

From this Table it will be seen that the available energy stored in any body of hot water will suffice to raise it to a height of 2 miles when the pressure is 150 lbs. per square inch, and to more than 3 miles when the pressure is 250 lbs. per square inch. In an explosion, only part of this energy is expended in tearing up the boiler and hurling the fragments about, but even a small fraction of it will suffice to do enormous damage. A few actual cases are stated in Table II, and a comparison is there drawn between the energy stored in boilers and the weight of gunpowder which is capable of producing an equivalent effect.

[1] Philosophical Magazine, vol. xxvi., 1863, p. 329.
[2] *Ibid*, p. 388.
[3] These results are abstracted from a Table given on pp. 656 and 657 of Prof. R. H. Thurston's "Manual of Steam Boilers," New York, 1888.

TABLE II.

Type of Boiler.	Dimensions of Boiler.	Working Pressure by Gauge.	Approximate Weight.			Available Energy.			Height to which Energy would lift Boiler.	Gunpowder equivalent to Total Available Energy.
			Boiler.	Water.	Steam.	Water.	Steam.	Total.		
	Length. Dia. Feet. Feet.	Lbs. per sq. in.	Tons.	Tons.	Lbs.	Foot-tons.	Foot-tons.	Foot-tons.	Feet.	Lbs.
Lancashire	27 × 7	100	12½	11½	46	93,000	2,351	95,351	7,628	795
,,	30 × 8	150	24½	17	110	200,991	6,606	207,597	8,473	1,730
Egg-ended	30 × 6	80	5½	10	88	64,740	4,083	68,823	12,513	574
Marine .	15 × 13	150	39	24½	100	289,663	6,005	295,668	7,581	2,464

In considering the principal causes of explosions which have occurred, each group will be dealt with separately, and will be illustrated as far as possible by actual cases in which there can be little doubt as to the primary cause of the explosions.

FAILURE OF BOILER-SHELLS.

External Corrosion of the Shells.—Some of the most disastrous explosions have been due to the external corrosion of boiler-shells. Such corrosion is nearly always due to dampness of the brickwork, and this dampness again may be due to leaky rivets, pipes or cisterns, or to drainage when the boiler is situated below the level of the surrounding ground. But whatever the original cause of the dampness, its action is aggravated by defective boiler-settings.

Case I is presented by an ordinary Lancashire boiler which burst near the back end at the right-hand side of the shell, *Fig. 1.* The rupture occurred in the first instance along the longitudinal line A B, where the plate had been eaten away by external corrosion for a length of about 3 feet, until it was as thin as a sixpence and too weak to resist the ordinary working-pressure. The position and extent of the corroded portion are roughly indicated by the shading, *Fig. 1*, while the manner in which secondary rents were developed from the primary one, a portion of the last belt of plating being opened out and torn through the sound plating at the adjacent circumferential seams, will be understood from the view given in the *Fig.* Fortunately, in this instance the secondary rents did not extend far, and

the case is a simple one; not only as to the relationship between the cause and the effect, but also in regard to the manner in which the corrosion was brought about. Turning to *Fig. 2*, which shows a cross-section of the external flues, it will be observed that the brickwork seating C D, upon which the boiler rested, was as much as 15 inches in width, so that corrosion of the plates at this part could take place to a considerable extent unobserved. Further, any moisture which leaked into the side-flue would naturally have drained to the point D, and thus have come into contact with the plates; while the great width of the bearing-surface afforded a secure lodgement for the water, and rendered it difficult for the heat passing through the flues when the boiler was working to drive it away. When it is added that subsequent enquiry elicited the fact that at the back end of the

Fig. 1.

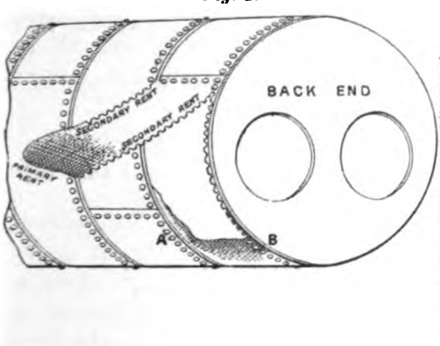
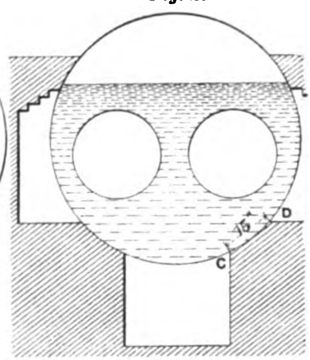


Fig. 2.



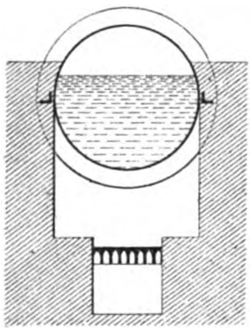
boiler, close to the part where the corrosion occurred, there was a jack-well, the water-level in which was above the floor of the side flue, the chain of causes leading to the explosion is completed. When the primary rupture in a boiler-shell is in a longitudinal direction and of serious dimensions, it is not often that the secondary circumferential rents which start from it stop within such moderate limits as in the case just considered; more frequently they start from each side of the initial rupture and run completely round the shell, occasionally forking and branching off in an irregular manner.

In some cases corrosion has occurred at the bottom of the shell where it rests on a broad mid-feather wall. This is a method of seating boilers which has been very fruitful of explosions, since the mid-feather is situated just at the part to which any moisture

on the shell, arising from leakage or other causes, naturally drains, while the excessive bearing-surface often allowed renders the mid-feather an objectionable receptacle for water, and permits the insidious work of corrosion to proceed unseen.

Case II, *Fig. 3*, shows a defective method of setting externally-fired boilers which frequently gives rise to trouble from corrosion —the sides of the boiler being swathed in brickwork to such an extent that as much as one-third of the entire circumference of the shell is hidden from view. The result in the instance illustrated was that leakage at a longitudinal seam kept the brickwork in the vicinity damp, and thereby set up the corrosion which led to the rupture of the shell. It will be noticed that the secondary rents do not always follow the seams of rivets or lines of natural weakness, but apparently rip through the solid plates with apparent facility.

Fig. 3.



External corrosion is comparatively slow in its action, at most about $\frac{1}{16}$ inch in twelve months; and, provided the boiler possesses an adequate factor of safety, a searching periodical inspection, at intervals of about a year, affords ample opportunity of detecting the ravages of external corrosion before it attains serious dimensions. To this end, therefore, the flues should be sufficiently capacious to admit of the passage of a man through them with ease, and the concealment of large areas of plating by brickwork should, as far as possible, be avoided. Broad seating-walls or mid-feathers are unnecessary. A bearing-surface of 4 to 5 inches is ample, even for the largest land boilers, and this surface should be afforded by fire-clay blocks specially made for the purpose, so as to raise the surface of contact above the floor of the side-flue and to keep it as dry as possible. The crowns of the side-flues should also be closed in with curved fire-clay tiles, having not more than two courses of bricks laid over them so as to hide as little of the plating as possible. Further, the jointing-material between the boiler and setting should be of fire-clay throughout, and not of common lime mortar, owing to the hygroscopic character of the latter material. Again, the longitudinal seams should be arranged, if possible, on the upper part of the boiler, clear of the brickwork, so as to be easily accessible for inspection or caulking. With small iron plates

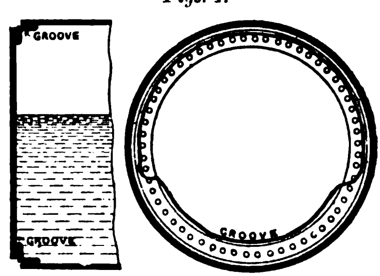
this was not formerly feasible, but with the introduction of steel plates of almost any size, no difficulty need now be experienced on this score. These points may perhaps appear somewhat trivial, but experience proves that they are too often ignored, and the consequences occasionally entailed by their neglect are very serious.

Internal Corrosion of the Shell.—Next in importance to external corrosion of the plates in contact with the boiler-seating, is the internal wasting of boilers from the action of the feed-water. The effects produced by this agency differ considerably in character, inasmuch as the points attacked and the nature of the corrosion vary. In some instances the plates are wasted away over their entire surface, in others the corrosion assumes the form of pits, varying in diameter between ½ inch and 2 inches, which may appear in groups or be widely scattered. The wasting due to internal corrosion is occasionally far more rapid than that due to external corrosion, and instances have occurred in which the metal has been so much reduced in the space of three years that no margin of safety remained.

From the foregoing it will be inferred that those explosions which, either directly or indirectly, owe their origin to internal corrosion, are not of a well-defined type. Reference may, however, be here made to a fact often revealed by explosions, viz., that external and internal corrosion sometimes run in parallel lines; as, for instance, in the vicinity of brickwork whose heat, when the water has been let out of the boiler, loosens the internal scale and exposes the bare plates to the action of warm moisture.

Combined Corrosion and Mechanical Action: Grooving.—When corrosion is accompanied by bending movements in the plates of a boiler, its wasting action is markedly intensified and a specific defect is developed of the character technically termed "grooving" or "channelling." An example of the failures arising from this cause frequently met with amongst cylindrical flat-ended boilers, is illustrated in *Figs. 4.* Sometimes these grooves form in the end-plate, sometimes at the root of the angle-bar ring or flange attachment. The groove results from the breathing action which often takes place in unstayed circular end-plates of this kind, in

Figs. 4.



consequence of variations of the steam-pressure. This gives rise to a local fretting action at the circumferential attachment, which, by splitting off the scale and oxide as fast as it is formed and exposing the raw plate to the action of the water or steam, greatly accelerates corrosion. The position of the groove depends upon the relative weakness of the end-plate and the attachment. If the end-plate is elastic while the angle-bar is stiff, the groove will be in the former, and *vice versâ;* or it may happen that the groove is formed in both at the same time, as in the particular case considered. The breathing and fretting action increases with the growth of the groove, which, when once started, develops with considerable rapidity, especially if the steam-pressure be subject to wide and frequent fluctuation. That the formation of these grooves is more the result of mechanical movement than of corrosive action will be evident from the fact that they form in the steam-space with almost as much rapidity as below the water-line, and they occasionally eat their way through the plate before other parts of the boiler exhibit any serious signs of wasting. In the cases considered, the grooving may be regarded as due primarily to weakness, and the failures would probably not have occurred had the ends been strengthened with bolt-stays or by other suitable means. It frequently happens, however, that grooving occurs as a consequence of excessive stiffness of the end-plates, particularly in Lancashire and Cornish boilers; and, though the defect is rarely in such cases a source of danger, a few words in reference to it may be not out of place. Such grooves are almost invariably situated near the crown of the furnace and follow the circle of the tube, sometimes in the end-plate and sometimes in the angle-bar or flange attachment, while the defect is always most severe at the front or furnace ends of the tubes. The grooving in these cases arises from lack of elasticity in the end-plates for the expansion and contraction of the furnace-tubes, and relief is often afforded, and further mischief prevented, by removing one or two of the lower rivets in the gusset wet-plates, so as to allow greater freedom of movement and to distribute the bending action over a wider area. In *Figs. 5* is shown a typical case of failure of a vertical boiler from grooving at the junction of the uptake with the crown of the fire-box. The uptake, it will be evident, acts as a strong central stay to the crown-plate, and in this instance when the stay, becoming insufficient to resist the working pressure, fractured, the fire-box crown proved incapable of bearing the additional load thrown upon it and collapsed, with the result that the boiler was shot up like a rocket and thrown to a considerable distance. It

should be mentioned that the attachment of the base of the fire-box to the shell was weak, and to this fact the grooving was in all probability largely due. *Fig. 6* represents a rather peculiar case of grooving in connection with another vertical boiler which exploded. In this case, the waste heat and gases were discharged through an opening in the side of the fire-box. There was no uptake, and the cambered crown-plate became, in consequence of its excessive pliability, grooved as shown at the convex corner of the flange which unites it to the vertical sides of the fire-box.

Figs. 5.

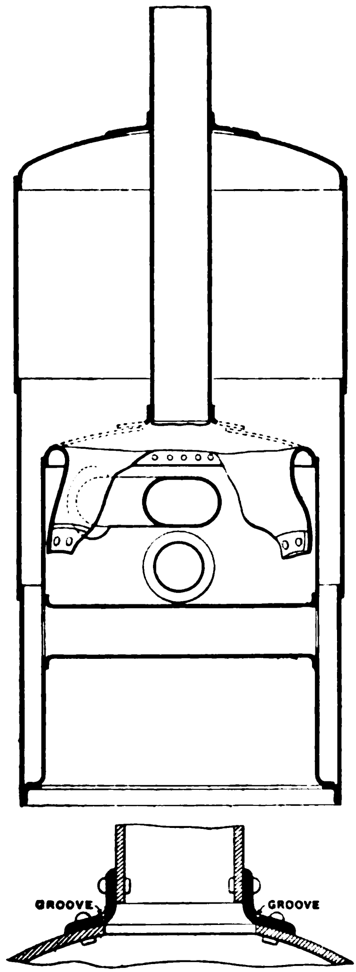
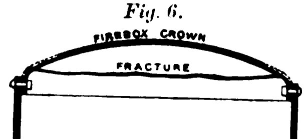


Fig. 6.

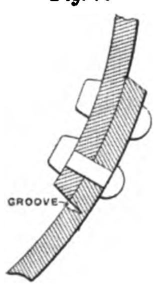


Grooving at Riveted Seams between the Shell and Tubes.—Grooving or channelling is occasionally found at the edges of the overlaps of the longitudinal or circular seams both of shells and of furnace-tubes. In the case of the longitudinal seams, the defect arises from the bending action due to the fact that the shell is not truly circular and that the couple set up by the stress in the plates tends to deflect the joint, the amount of deflection varying with the steam-pressure. The action is more pronounced in boilers of small diameter with a narrow single-riveted overlap than in those of large diameter having double-riveted overlap seams; it is also, as in other cases, promoted by wide and frequent fluctuations of steam-pressure; and in some instances is doubtless started by the injudicious use of caulking-tools. In the case of the ring-seams, the bending action which gives rise to grooving arises from arching of

the shell or of the furnace-tube in consequence of unequal expansion.

Grooving in Locomotive Boilers.—It seldom occurs that grooving at the riveted seams of stationary boilers is of a very serious character or gives rise to an explosion. In locomotive boilers, however, it assumes such an aggravated form as to constitute a specific defect of a dangerous kind. A larger number of disastrous explosions of locomotive boilers have arisen from grooving than from all other causes put together. In locomotives, the grooving is confined almost exclusively to the longitudinal seams, and its active character is due to the fact that the barrels are of small diameter and that the steam-pressure is liable to large and sudden fluctuations; while the deformation at the joint is intensified by the jolting to which the boiler is subjected in its transit over the permanent way. Grooving is not confined to single-riveted seams, and double-riveted seams do not afford absolute security. In a few instances on the North Eastern Railway, the groove, *Fig. 7*, was so fine that it must have been almost invisible before the explosion; and its appearance even suggested that it might be a fracture of a brittle plate. That, however, was not the case, nor could the grooving have been started by careless caulking, as all the seams were caulked outside only.[1] In all the cases of explosions of locomotive boilers from longitudinal grooving, the defect has invariably been associated with riveted joints of the ordinary overlap form, and no case of grooving has been met with where the joints were of the double butt-strap type. With a view to the detection of this defect the longitudinal seams should always be placed in the steam-space, so as to be easily accessible for examination.

Fig. 7.



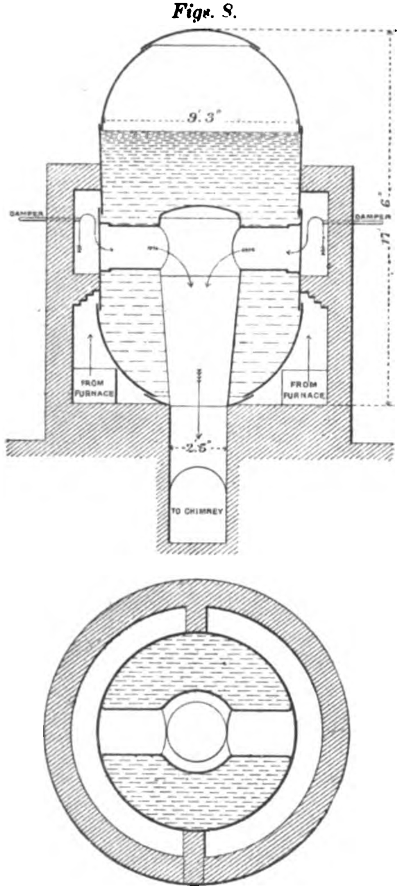
Stresses arising from unequal Expansion and Contraction, in externally-fired Boilers.—The severity of the stresses produced by differences of temperature may be inferred from the fact that long plain cylindrical boilers will occasionally rend at a circumferential seam with hardly any premonitory warning. The tendency of boilers which are only heated along the bottom of their shells is to curl up at their ends, while the introduction of cold feed-water, which naturally gravitates towards the bottom, produces severe stresses in an opposite direction. Fractures consequent thereon are sometimes found to run from the rivet-holes to the edge of the

[1] For further particulars, see Report of the Chief Engineer of the Manchester Steam Users Association, December, 1880.

overlap, and sometimes from hole to hole. In the latter case they are rapidly developed into "seam-rips" when the boiler is subjected to the racking stresses of actual work.

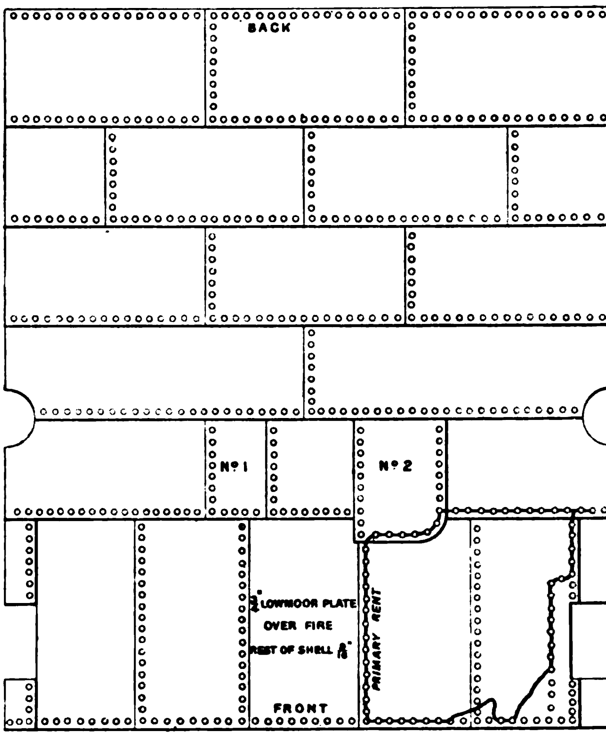
Rastrick Boilers.—The remarks as to the dangers of externally-fired boilers are also applicable to a large extent to boilers of the Rastrick type, which are often adopted at ironworks for utilizing the waste heat of puddling-furnaces and which have been productive of some of the most disastrous explosions on record. *Figs. 8* show the general arrangement of this type of boiler. The shell is practically of the plain egg-ended type set upright, and the flames, after playing on this in the first instance, pass through two, and sometimes through four, short cross-tubes (according to the number of furnaces) into a central descending flue-tube, whence they are led to the chimney. The quantity of heat passed off from puddling-furnaces is not great but it is of an intense character, and its local impingement on the vertical plates of the shell, which are necessarily thick on account of its large diameter (ranging in some cases up to nearly 10 feet), gives rise to over-heating and to serious distress at the riveted joints, which suffer much from lap-fractures and occasionally from seam-rip. The sulphurous fumes which are passed off with the gases from the furnaces also prove destructive, by causing a rapid corrosion of the plates over their entire surface. This corrosion is often not apparent to the untrained eye, and is only capable of being detected by careful examination of the rivet-heads and of the edges of the overlaps.

Figs. 8.



A brief reference may here be made to a specially interesting case of failure of an externally-fired boiler, which presented a unique feature, inasmuch as the explosion occurred two hours after the fire had been drawn and while the pressure was considerably below its maximum. The boiler was fired under the bottom, and the waste gases were ultimately led through two internal flue-tubes. The feed-water produced a sediment, and three months after the boiler had been set to work, leakages at the ring-seam over the bridge

Fig. 9.

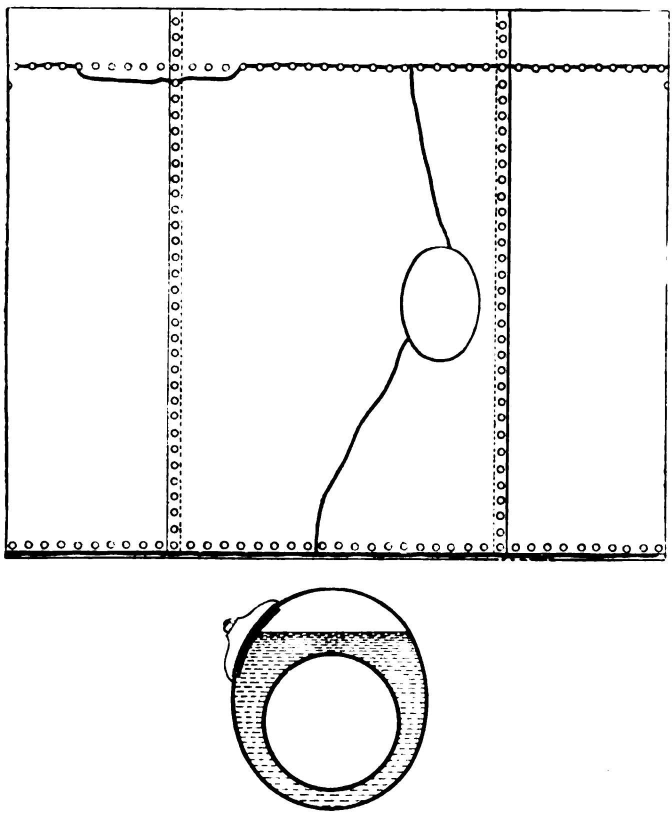


became so serious that patch No. 1, *Fig. 9*, had to be fitted. Shortly afterwards patch No. 2 had to be added; but this did not stop the leakage of the seams between the thick and the thin plates, one of which ultimately tore as shown in the *Fig.* when the boiler was only two years old.

Insufficiently Strengthened Holes in Shells.—Many explosions owe their origin to local weakness caused by large man-holes or dome-holes being cut through boiler-shells and the omission of com-

pensating rings or the provision of inefficient ones, see *Figs. 10.* The weakness thus produced was clearly demonstrated in hydraulic experiments carried out in 1874–76 by the Manchester Steam Users Association,[1] when a Lancashire boiler gave way at the man-hole under a pressure of 200 lbs. per square inch, although the estimated

Figs. 10.



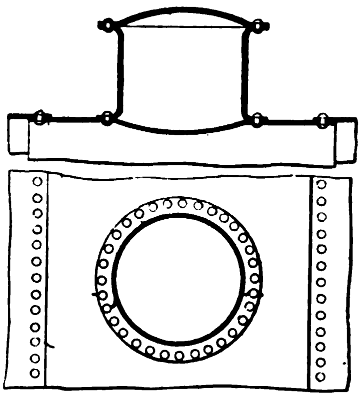
bursting-pressure for a seamless shell without the hole was 466 lbs. per square inch. On this occasion, the mean circumferential stress did not exceed 8·6 tons, whereas the material had been proved capable of withstanding a stress of 20·6 tons per square inch. Another test was made with a small wrought-iron neck

[1] See also *Engineering*, vol. xxi., 1876, p. 237.

M 2

riveted round a 17-inch circular opening, *Figs. 11*; but the boiler gave way at that point when the pressure had only reached 250 lbs. per square inch, which is very low having regard to the sectional-area of the compensating material. From this it is evident that the sides of a dome cannot be depended upon to add materially to the strength of a boiler-shell which has been locally weakened by a large hole; and even where the opening is small, the presence of a dome seriously affects the strains in the boiler-shell. Another experiment was carried out with a cast-iron mouthpiece fitted round a hole 20 inches in diameter, but although its sectional-area was 30 square inches, as against 8¾ square inches of the removed boiler-shell plate, this part gave way at a pressure of 200 lbs. per square inch, proving that cast-iron is an unsuitable material for man-hole mouthpieces.

Figs. 11.



Collapse of Boiler-Flues.

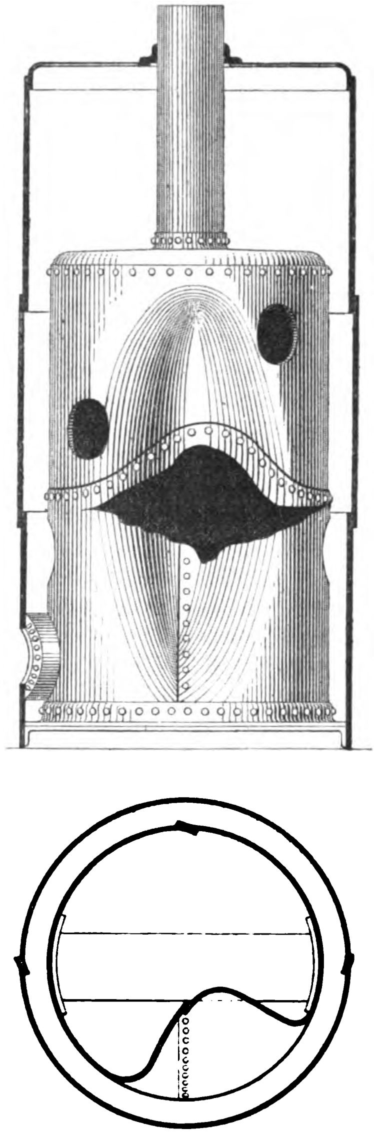
Until Sir W. Fairbairn made his well-known experiments on boiler-flues, little was known about the strength of flues; and, although it had been previously shown mathematically that a departure from the cylindrical shape seriously weakened them, he was the first to demonstrate experimentally that the length of flues was an important factor in estimating their resistance to collapse. Nearly all boiler-flues are now fitted with strengthening rings, and the best manufacturers ensure a perfect cylindrical shape, either by welding the longitudinal seams or by making them with double butt-straps. In the tests conducted by Sir W. Fairbairn, the experimental tubes bent during collapse until their cross-sections assumed star-shaped forms.[1] Professor W. C. Unwin has shown that the number of depressions in the circumference of the tube increases as the ratio between its length and its diameter diminishes.[2]

[1] "On the Resistance of Tubes to Collapse," Phil. Trans. Roy. Soc. 1858, p. 389.

[2] "On the Resistance of Boiler-Flues to Collapse," Minutes of Proceedings Inst. C.E., vol. xlvi. p. 225.

In actual practice, however, the collapse nearly always consists of a flattening of one or two sides. Generally the top of the furnace gives way, the crown of the tube is crushed down until it follows more or less the sweep of the lower portion. The prevalence of this kind of collapse is due to the fact that the crown of the tube is usually the part most seriously affected by the fire as well as by corrosion. Occasionally the bottom of the flue is crushed upwards, the crown remaining convex; and sometimes the crushing affects the sides. *Figs.* 12 show a typical example of collapse often met with in boilers of the small vertical type; and similar effects are sometimes produced in vertical chimney boilers, the flues of which should always be strengthened by hoops. Cases have been noticed where such rings having been originally fitted have been removed during repair of the boiler, or perhaps have been replaced by a few stays.

Figs. 12.



COLLAPSE OF FURNACES.

Overheating through Shortness of Water.—To whatever cause shortness of water may be due, its effect is always the same. As the water-level is lowered, the furnace-crowns are exposed to the weakening influence of a gradually-increasing temperature and ultimately bulge down. Such collapses usually occur in one furnace only of a pair, as might be expected; since

the fires, unless mechanically stoked, are never charged simultaneously. The results of such collapses are rarely of so serious a nature as those previously mentioned; and the Author can remember only one case, during the last twenty years, in which shortness of water in Lancashire or Cornish boilers has led to the destruction of the shell. The risk of serious rupture in the event of collapse from overheating is much diminished when the tube is strengthened by encircling rings; and cases have occurred in which the tubes have been seriously overheated and even crushed, but were prevented from tearing by their strengthening rings.

Whilst referring to the diminution of risk of rupture, a word or two may be not out of place with respect to one or two precautionary measures against shortness of water. Chief of these is the fitting of duplicate water-gauges, so that one may serve as a check on the other, and diminish the chances of misreading. Valuable supplements are a low-water safety-valve and a fusible plug. Carelessness will account for some mishaps, and the water has repeatedly been accidentally run out of a boiler by the blow-off cock being opened; such cocks should always be fitted with a safety-guard to prevent the removal of the key except when the cock is closed.

When several boilers are fed from one pump, particularly when there is a difference of pressure in the various boilers, and one of the check-valves becomes accidentally jammed, the water will readily be siphoned from one boiler into another; and to prevent this, the feed-pipes which supply a group of boilers should be placed so as to deliver 3 inches or 4 inches above the furnace-level.

Whether overheating be the result of slow evaporation or of rapid exposure of the furnace-crowns through some misapplication of the feed or blow-off, the character of the collapse is practically identical, and shows the same local peculiarities. If the boiler is of the Lancashire type, both furnaces generally show marks of overheating—a distinct purple bloom being generally visible on the fire side of the collapsed part, showing the level to which the water has sunk and the extent to which the plates have been overheated. If the overheating be excessive, this is corroborated by discoloration of the plates on the water side also, though seldom to the same extent. The only reliable experiments relating to the strength of overheated flues are those conducted by the Manchester Steam Users Association, and to which reference has already been made. In one of these tests, which was conducted under a pressure of 40 lbs. per square inch, the water-level was lowered by opening the blow-out tap until nearly half the circumference

of each furnace-tube was laid bare.[1] The time occupied in exposing an arc of the tube having a versed sine of 15 inches was four minutes, and in six minutes after this, *i.e.*, ten minutes from the time of the water being level with the crowns, one tube collapsed. What was the precise temperature attained by the furnace it is impossible to say, but there can be little doubt that it was red-hot, since some fusible disks attached to the furnace-crowns, as well as some lead strips laid loosely across them, were fused. Some gauges attached to the furnaces afforded a means of watching the rapidity with which the collapse took place; and observation showed that under the conditions of the test, with a large extent of surface quickly exposed and heavy fires, there is very little warning, and when once bulging begins it is followed by complete collapse in the course of two or three seconds.

In a subsequent test, the water-level was lowered and the crowns of the furnace-tubes were laid bare by the action of evaporation, in a manner approximating to that which generally occurs in practice in cases of scarcity of water. With a view to form some estimate of the temperature attained by the plates over the fire, fusible gauges of tin, lead, and zinc were attached to each furnace-crown, while lead strips were also bound in position at intervals throughout the length of each tube. In this experiment the water was brought down to the level of the furnace-crowns by opening the blow-out tap. The tap was then shut, the fires were heavily charged, and the furnace-crowns were permitted to become exposed by evaporation. In twenty-three and a half minutes, all the fusible gauges attached to the furnace-crowns having melted, the feed was turned on through a pipe fixed immediately over the furnace-crown, and perforated on the under side so as to play in a series of fine jets upon the overheated plates, the injection of the feed being at the rate of about 28 gallons per minute. The only effect of this was to reduce the pressure, which fell in two and a half minutes from 28½ lbs. to 26 lbs. per square inch. The whole bearing of these, as well as of the other tests of the series, showed that the popular notion with respect to the danger of turning on the feed in the event of shortness of water is erroneous.[2]

Reference has been made to the effect of shortness of water in

---

[1] The boiler was of the Lancashire type, 27 feet 9 inches long and 7 feet in diameter, with plain tubes measuring 3 feet in diameter and $\frac{7}{16}$ inch in thickness.

[2] For a complete record of these tests and explanatory illustrations, see "Report on a Series of Red-hot Furnace-crown Experiments," by the Chief Engineer of the Manchester Steam Users Association, 1889.

boilers of the Lancashire and Cornish types only; but failures from this cause are not exclusively confined to such boilers. Collapse of locomotive-boiler fire-boxes sometimes occurs, though happily rarely—a fact due partly to the superior attention which boilers of this class receive, and partly to the efficient manner in which the roofs of the fire-boxes are supported, in consequence of which a warning of overheating is generally afforded before the danger becomes serious. In boilers of the multi-tubular marine type the furnace-tubes are in a somewhat similar way protected against collapse; since it would be almost impossible to lower the water-level to such an extent as to lay bare the furnace-crowns without attention being drawn to the fact. In such an event the whole of the smoke-tubes would be first uncovered, and even before this, serious trouble would be experienced with the crown of the combustion-chamber and the smoke-tube ends in the tube-plates. Nevertheless, the furnace-tubes of marine boilers occasionally collapse through overheating, which does not, however, arise in these cases from deficiency of the water-supply.

Again, in boilers of the small vertical type, deficiency of the water-supply is generally revealed by collapse and rupture of the uptake before the water-level can be so far reduced as to jeopardise the safety of the fire-box; although, as the uptake acts as a substantial stay, its failure in some instances causes the crown of the fire-box to collapse downwards in its turn. In boilers of the plain egg-ended type, the water may fall to a very low level without risk of serious overheating; and failures from shortness of water pure and simple are seldom met with, since the straining and leakage at the seams of rivets afford warning of the danger. A few instances, however, have come under the Author's notice, and their characteristics may be briefly referred to. One of these showed discoloration on each side of the shell over the fire, indicating that the water in the boiler had been boiled away until there was only a depth of about 6 inches at the time of rupture; when the left-hand side ripped for a length of 4 feet 6 inches, forming an opening about 2½ inches wide in the middle with distinct lips on each side, which showed it had been produced while the plate was in a plastic condition. As an illustration of the statement that the water is the main factor in the work of destruction, it may be noted that in this case the boiler was not stirred from its seat, its contents consisting almost entirely of steam, which escaped through the opening as from a fractured pipe. Had the boiler been filled with hot water to its normal level, a rupture of such magnitude would in all probability have

resulted in the complete destruction of the boiler and its seating. It may be well to add, however, that the rapid lowering of the water-level, say, from fracture of the blow-out pipe or other similar cause, may, in the case of a boiler of this type, which is fired hard and severely strained, precipitate a disastrous explosion; and the Author has met with one very striking instance of this.

Cases of overheating and rupture often result from the presence of soluble salts or mechanical impurities, grease, &c., in the water, and occasionally even from imperfect circulation due to improper design. In marine boilers using salt water, the neglect to blow out is often the cause of collapsed furnace-crowns, the density of the water gradually increasing until it reaches a maximum, when salt is precipitated upon the plates in a solid state. This, being a bad conductor of heat, soon interferes with its transmission to such an extent as to cause the plates to soften and collapse under the ordinary working pressure, even although there may be a copious supply of water in the boiler, and although the structure may possess a fair factor of safety.

In some vertical boilers the effects of overheating are most visible at the bottom of the fire-boxes, which are bulged inwards all round their circumference, forming a series of pockets at the level of the fire-bars.

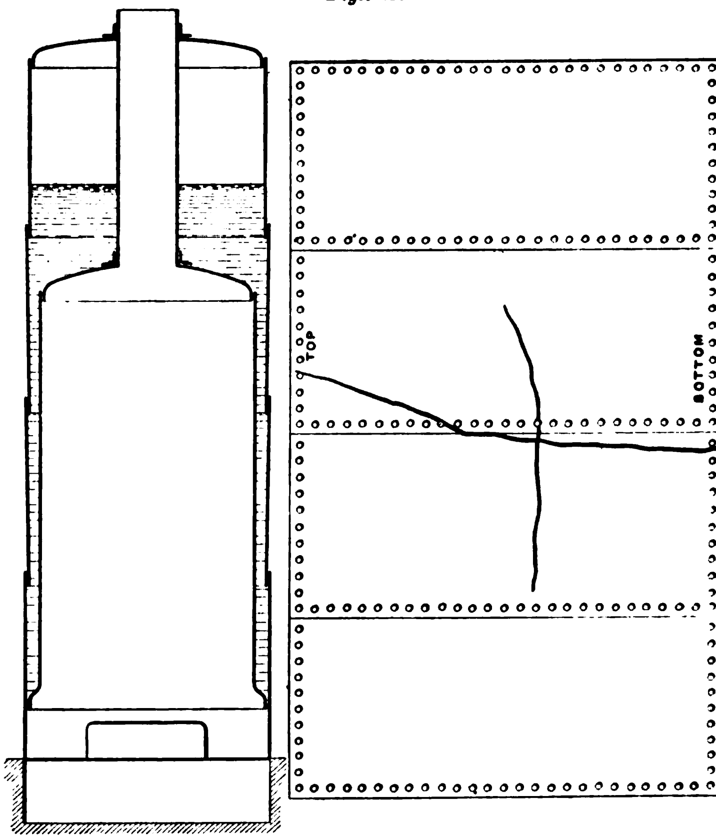
In land boilers, the carbonates and sulphates of lime and magnesia are the most frequent source of overheating of the kind described, especially when those salts are associated with grease. Considerable attention has been directed to the action of these impurities in consequence of the numerous and puzzling cases of failure of the furnaces of high-pressure marine boilers, using fresh water and supplying steam to surface-condensing engines. Professor Vivian B. Lewes[1], however, has shown that the trouble arose mainly from the presence of oily matter in the water carried over from the engines. A point to be noticed in such cases of overheating is its gradual character compared with overheating from shortness of water. In the case of furnace-tubes, the point of maximum heating occurs oftener at the haunches than at the crown, so that the cross-section of the collapsed tube presents two points of depression instead of one. This peculiarity does not however invariably occur, and is more noticeable in the early stages of distortion than after complete collapse and rupture have occurred.

As already remarked, overheating may occur as the result of in-

[1] Transactions Inst. of Naval Architects, 1891, p. 67.

adequate circulation from defective design of the boiler. As an example, the Author cites the case of a boiler of the ordinary vertical type, *Figs. 13*, in which the annular water-space surrounding the fire-box was exceedingly narrow, viz., 2 inches to 3 inches for a depth of 9 feet 6 inches. This space was insufficient to permit of satisfactory circulation, the consequence being that when the

Figs. 13.

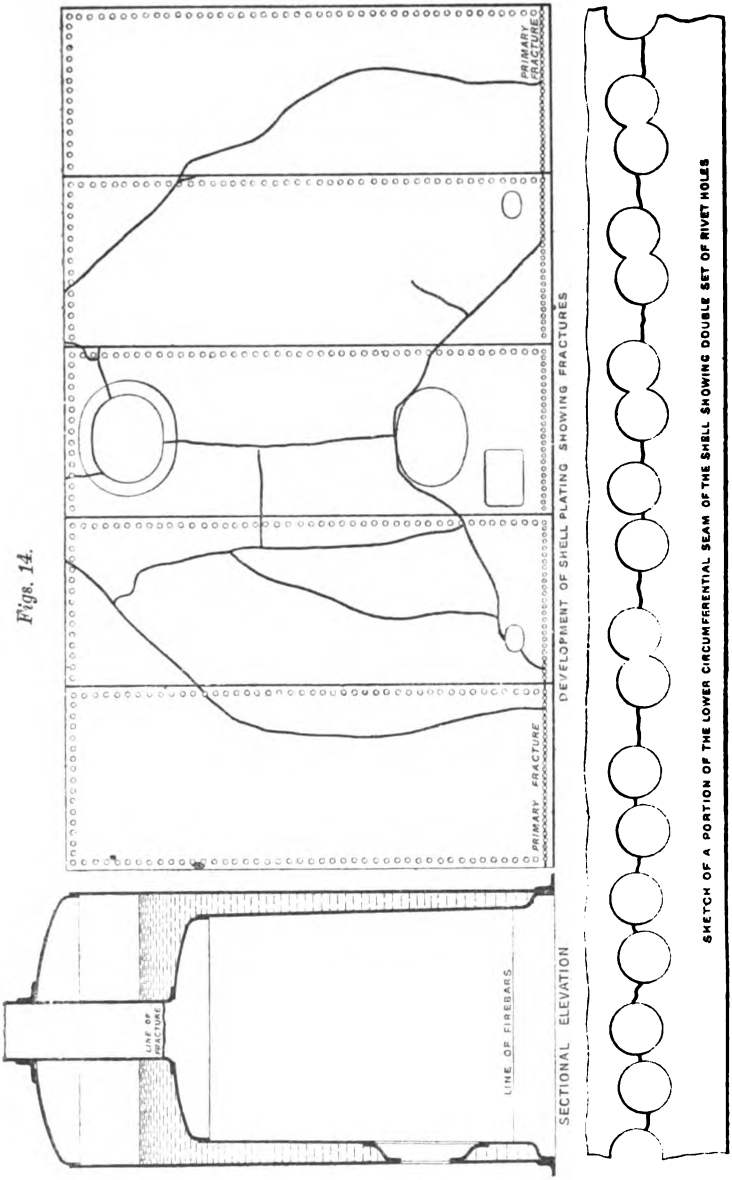


boiler was at all forced, the up-cast current of steam, which was generated in the lower part of the boiler, interfered seriously with the current of water flowing downwards to take its place. The fire-box was consequently surrounded by foam rather than by water, and, as might have been expected, the plates became overheated. The boiler gave trouble from the commencement, and soon after being set to work bulges or pockets began to be formed inside the

fire-box at the fire-bar level. Stud-stays were inserted across the annular space at this part, with a view to prevent the formation of the pockets, but the attempt proved unsuccessful, and the fire-box eventually collapsed and was torn open from top to bottom. Numerous cases of overheating from a similar cause have been recorded in connection with certain types of sectional tubular boilers. The boiler formerly known as the Howard sectional boiler was very defective in this respect, especially in its earlier form. Considerable improvement has during recent years been made in the design of tubular boilers, but, taken as a class, their employment is not desirable when the water is heavily charged with lime salts or other impurities.

Over-pressure.—Explosions due to the pressure in the boiler becoming, from any cause, greatly in excess of the ordinary working pressure are in all cases associated with the defective operation of the safety-valve. This fitting is defective if it is capable of being overloaded, either by accident or design, or if the valve may become jammed down upon its seat by the insertion of a wedge between the upper side of the lever and the top of its guide, or by the spindle, in cases where there is a waste-pipe above the valve, becoming rusted in the hole of the cover. Valves of the pendulous dead-weight type are much to be preferred to those of the lever type. For locomotive boilers, valves loaded by the direct action of a spring are preferable to those in which levers and spring-balances are employed. These latter valves have been productive of more explosions from excessive pressure than have occurred from all other causes combined. Their action provides for the variation of the pressure on the valve by increase of tension in the spring. This is effected by a thumb-nut upon a screw, and there is nothing to prevent either this nut being screwed on until after the spring has become fully extended, or the insertion of a plug between the pointer and the top of its guide, by both of which means it is possible to jam the valve firmly down upon its seat. The grouping of the safety-valve and the stop-valve upon a common outlet, especially if the boiler be one of a series, is to be avoided, on account of the ease with which the plugging of the hole in the shell from the inside, when the boiler is under repair, may pass undetected. Two very disastrous explosions have arisen in this way. Even in cases of boilers in which the pressure is little if at all above the atmospheric pressure, safety-valves should not be omitted, as provision should be made for an accumulation of pressure which may occur at any time, due to the outlet becoming choked or to some other cause.

Figs. 14.


DEVELOPMENT OF SHELL PLATING SHOWING FRACTURES
PRIMARY FRACTURE
PRIMARY FRACTURE
SECTIONAL ELEVATION
LINE OF FRACTURE
LINE OF FIREBARS
SKETCH OF A PORTION OF THE LOWER CIRCUMFERENTIAL SEAM OF THE SHELL SHOWING DOUBLE SET OF RIVET HOLES

Faulty Material and Construction.

In regard to an explosion which occurred within six months of its being first put to work, of a Lancashire boiler, built of "Best" iron (which, as is well known, is of poor quality), in which the holes were punched before the plates were bent, the nature of the fracture showed that they had been partially cracked along a line of rivet-holes in one of the longitudinal seams. Mild steel has now almost entirely superseded inferior iron, and in most works the plates are drilled after being bent. In another case in which a boiler-shell burst from over-pressure, a case of gross carelessness of construction was revealed, the seam which gave way having at first been punched in at the wrong points, and subsequently punched again along the same line, *Figs. 14.* The defect was then covered by an iron angle-bar. In both of these cases a searching hydraulic test would probably have revealed the defective construction.

Conclusion.

In presenting this account of the scientific and engineering features of boiler-explosions, the Author feels that he has imperfectly accomplished his task. The subject is so wide, and is so intimately linked with every detail of the design and construction of boilers, that its exhaustive treatment is impossible within the limits of a single Paper. Many details of importance have necessarily been passed over, but the Author trusts that the facts and statements contained in the Paper, which have been collated during the course of a somewhat unique experience, may possess sufficient interest to the Institution to warrant the attempt he has made.

The Paper is accompanied by numerous drawings and tracings, from a selection of which the *Figs.* have been prepared.

[Discussion.

Discussion.

Mr. Wolfe Barry.

Mr. J. Wolfe Barry, C.B., Vice-President, in moving a vote of thanks to the Author, said the subject treated was of such importance as to warrant a careful and painstaking discussion, concerning as it did the welfare and safety of so many persons.

Mr. Longridge.

Mr. Michael Longridge remarked that the subject of boiler explosions had occupied the attention of the Institution on previous occasions. He believed that two Papers on the subject had been read, both of them some time ago, and both by foreigners. In the first[1] the theory advanced was that boiler explosions were due in almost every case to the sudden development of a highly explosive force in the lower part of the body of water in the boiler. This force acted with such suddenness as to tear the bottom out of the boiler before it had time to propagate itself as far as the safety-valve and be relieved thereby. The remedy proposed was a pipe from the bottom of the boiler, with a safety-valve which should receive the impact of the explosion and so save the boiler from destruction. The discussion on that Paper was of a highly imaginative character. The second[2] Paper was by Mr. W. K. Hall, and in it boiler explosions were attributed to the plates becoming over-heated, and to the heat being communicated from them to the steam, which thereby became highly surcharged with caloric. In this dangerous state Mr. Hall conceived that the small quantity of water injected into that highly surcharged steam would produce an explosion which he compared to the momentum of a blow. It was asserted that in many cases the water was supplied from the body of the water in the boiler itself by the agitation incident to the opening of the safety-valve, and thus it was considered that the very appliance which was fitted to the boiler in order to save it was really the cause of its destruction. The remedy suggested was a blow-off valve actuated by a float, which, whenever the water in the boiler fell below normal level, should open and allow the whole of the water to run out of the boiler, thereby allowing it to be over-heated at leisure without doing any harm. At the conclusion of the discussion the President informed the members that it was unnecessary to invent far-fetched theories to account for

[1] Minutes of Proceedings Inst. C.E., vol. i. p. 103.
[2] *Ibid.* vol. xv. p. 281.

boiler explosions, since they resulted from simple causes which could nearly always be ascertained by making a post-mortem examination of the boiler. The present Paper gave an account of these causes; but he desired to mention one, viz., the hydraulic test, which the Author had omitted, but which he knew had been fruitful of more than one explosion. He earnestly cautioned the members, who he believed were somewhat apt to prescribe that test, to consider well before doing so. A hydraulic test was a test of workmanship and of the strength of parts which could not be submitted to calculation, such as flat surfaces or oval flues; but Mr. Longridge.

Fig. 15.

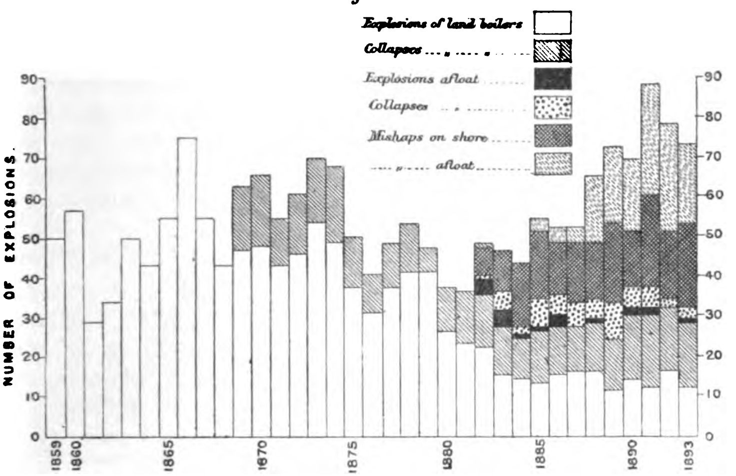


DIAGRAM SHOWING NUMBER OF BOILER EXPLOSIONS DURING THIRTY-FIVE YEARS, 1859–1893.

as a test of the strength of boiler-shells or of other structures which could be submitted to calculation it was very dangerous.

He desired rather than to further criticise the Paper, to supplement it by a brief statement of the extent of the evil under discussion, and the means whereby it might be abated. With regard to its magnitude, *Fig. 15* showed the number of explosions for each year from 1859 to 1893; and *Fig. 16* the number of deaths resulting from those explosions. It would at first sight appear from the *Figs.* that if less fatal boiler explosions were now more frequent than in former years. This was not the case. The apparent increase was due to several causes, but the following were the most important:—1st. In the earlier years the records only included explosions of land boilers, and were far from being complete; 2nd. Since the

Mr. Longridge. passing of the Boiler Explosions Act in 1882, in addition to explosions and collapses of flues both on land and afloat, a number of mishaps of various kinds had been included in the returns, for under that Act "any closed vessel used for generating steam, or for heating water, or for heating other liquids, or into which steam is admitted for heating, steaming, boiling, or any other similar purpose" was held to be a "boiler." The effect of this was apparent from *Fig. 15*, which showed that if the areas representing the explosions and collapses afloat, and the numerous mishaps both on shore and on board ship were excluded, the

Fig. 16.

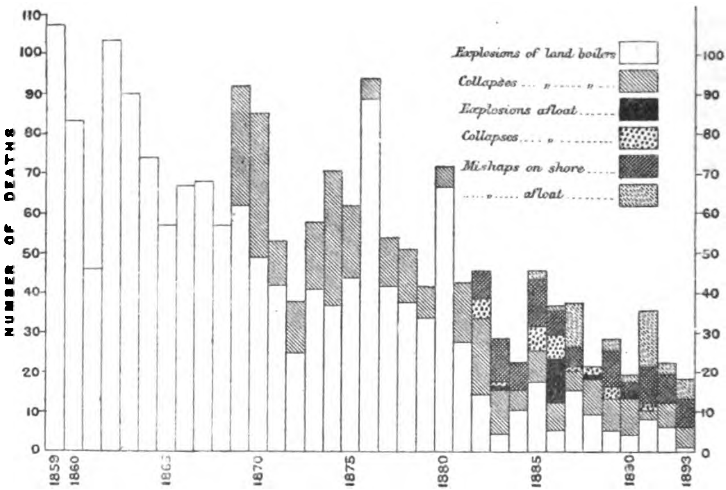


DIAGRAM SHOWING NUMBER OF DEATHS FROM BOILER EXPLOSIONS DURING THIRTY-FIVE YEARS, 1859–1893.

remaining areas, representing the explosions and collapses of flues of land boilers, instead of being greater were now less than in former years. *Fig. 16* also, representing the deaths resulting from these explosions, collapses, and mishaps, showed the very marked improvement. Indeed, this diagram proved that whatever the state of affairs had been twenty years ago, it was now fairly satisfactory. In 1893, for example, one death only had resulted from explosions of land boilers. Five deaths had, however, resulted from collapses of furnaces or flues of land boilers, and in this respect, no doubt, there was room for improvement, though so long as men were careless and intemperate, he feared collapses would occur. In addition to these there had been seven deaths from

miscellaneous mishaps on shore and five from those at sea. These mishaps were almost as disastrous as boiler explosions themselves, and it was difficult to ensure their prevention. They included all kinds of accidents, such as the melting of fusible plugs, the blowing out of joints, fractures of tubes, steam-pipes or stop-valves, explosions of drying-cylinder ovens, tar-stills, and many other casualties. Among the most fatal of these had been the fractures of copper steam-pipes, that on board the "Elbe" in 1887 having resulted in ten, and that on board the "Jumna" in 1891, in seven deaths. As to the question of reducing the number of explosions, he believed, of the different systems of inspection, that by private associations and insurance companies, as now in operation in England, was by far the best. It was, as was proved by the figures in Table III, efficient and elastic. Tables III and IV gave the numbers and causes of explosions, collapses, mishaps and deaths which had occurred since the passing of the Boiler Explosions Act in 1882, a period of eleven and a half years. The total number of boilers in use during that period had been estimated at 140,000. Table III also showed the numbers Mr. Longridge.

TABLE III.—BOILER EXPLOSIONS DURING ELEVEN AND A HALF YEARS FROM JUNE, 1882, TO DECEMBER, 1893.

—	Numbers.	Deaths.
Explosions of land boilers	152	86
Collapses „ „	151	73
Explosions afloat	14	16
Collapses „	55	21
Mishaps on land	184	78
„ afloat	140	40
	696	314
Yearly average . . .	60·5	27·3
Of these the following occurred to insured boilers:—		
Explosions	23	27
Collapses	50	28
Mishaps	31	10
	104	65
Yearly average . . .	9·0	5·7

Mr. Longridge. TABLE IV.—PARTICULARS OF BOILER EXPLOSIONS DURING ELEVEN AND A HALF YEARS FROM JUNE, 1882, TO DECEMBER, 1893.

Type of Boiler.	Land Boilers. Number of Explosions.	Land Boilers. Number of Collapses.	Marine Boilers. Number of Explosions.	Marine Boilers. Number of Collapses.
Plain cylindrical	42			
Locomotive and portable . .	31	13		
Cornish . . .	24	39		
Vertical with internal fire-box .	17	67	6	21
Hot water . .	16	2	..	..
Lancashire . .	11	17	..	..
Rastrick . . .	2	..	..	..
Wagon . . .	2	..	..	..
Fuel economiser .	2	..	..	..
Galloway . . .	..	6	..	..
Chimney . . .	..	3	..	..
Miscellaneous .	5	4	..	..
Marine . . .	..	..	3	26
Return-flue . .	..	..	5	8
	152	151	14	55

Cause.	Land Boilers. Number of Explosions.	Land Boilers. Number of Collapses.	Marine Boilers. Number of Explosions.	Marine Boilers. Number of Collapses.
Corrosion, external	43	17	2	1
" internal	11	21	..	3
" on both sides . . .	..	..	6	..
Corrosion, side not stated . . .	8	24	..	4
Grooving . . .	23	2	..	..
Excessive pressure	14	16	..	9
Outlets frozen or blocked . .	12	2	..	..
Failure of stays .	9	3	..	2
Deficiency of water . . .	9	37	..	13
Structural weakness . . .	9	17	..	3
Fractures . . .	5	..	..	..
General deterioration . . .	5	..	4	..
Seam-rips . . .	2	..	..	..
Deposit . . .	1	8	..	17
Not ascertained .	1	4	2	3
	152	151	14	55

relating to the 70,000 boilers which had been inspected during this period by the Boiler Insurance Companies. It would be seen that there had been twenty-three explosions and fifty collapses, giving an annual explosion rate of 1 in 11,000 boilers insured. The explosions had caused twenty-seven deaths and the collapses twenty-eight deaths, so that the annual death-rate had been but 1 in 14,600 boilers. These were results which, so far as he knew, had not been attained under government or compulsory inspection in any country except Holland. With regard to the 140,000 boilers, whether inspected or not, 196 deaths had resulted from

explosions and collapses in eleven and a half years, or one death per annum for every 7,100 boilers. Deducting from these totals the number of insured boilers, and of the deaths resulting from explosions of them, there appeared to be one death per annum for every 5,000 boilers not under inspection, a death-rate nearly three times as high as among inspected boilers. It was necessary, therefore, to have these boilers brought under the inspection of existing companies or of other companies working on the same system, and this he thought would be gradually brought about with the assistance of the Board of Trade without resorting to Government inspection. Mr. Longridge.

Sir FREDERICK BRAMWELL, Bart., Past-President, asked whether Mr. Longridge had included explosions of domestic boilers in *Figs. 15* and *16* and Tables III and IV. Sir Frederick Bramwell.

Mr. LONGRIDGE replied that they were included in the "mishaps."[1] Mr. Longridge.

Mr. H. H. WEST was much impressed with Mr. Longridge's remarks with regard to the inclusion in the returns of mishaps of all kinds, whether they were really boiler explosions or not. A case in point had been afforded by a vessel that he was concerned with which went into a harbour for shelter on account of bad weather. It became known that the joint of the feed-chest cover had blown out, and having but one boiler, the engineers had availed themselves of the shelter to remake the joint. He believed that would be recorded as an explosion. One of the causes of explosion referred to in the Paper did not occur so often in marine boilers as in land boilers, for the reason that the former were in almost all cases free from brickwork, which was a great source of corrosive influence on the outsides of the plates. There was much importance in another point which Mr. Longridge had referred to—skilled supervision. Nearly all marine boilers were under skilled supervision. In every steamer there was a skilled engineer—several in most cases—in charge of the boilers which were surveyed by Lloyd's or by the Board of Trade, and in addition by the company's marine superintendent; so that explosions of marine boilers were comparatively rare. That would be seen very markedly from the diagrams that Mr. Longridge had prepared, *Figs. 15* and *16*. He was indeed somewhat surprised to see them so considerable as they there appeared. He would like to know what had been the circumstances which had caused the large number of deaths indi- Mr. West.

[1] Mr. Longridge subsequently stated that his answer had been incorrect. Explosions of kitchen boilers in private houses were not included in the Tables. Hot-water boilers for heating churches, schools, and other buildings had been included among the explosions and collapses.—SEC. INST. C.E.

Mr. West. cated by the long black mark in the year 1886, *Fig. 16*, and also whether the number of deaths was counted from the bottom of the black mark or from zero.

Mr. Longridge. Mr. LONGRIDGE said that the length of the black mark itself was proportionate to the number of deaths, which were not counted from zero. He could not remember which explosion it referred to.[1] As regarded steamships inspected by the Board of Trade the explosion rate among those vessels was, he believed, about 1 in 6,770 boilers, which was considerably greater than the rate of explosion among the voluntarily inspected boilers.

Mr. Wingfield. Mr. C. H. WINGFIELD observed that in Table II, showing the amounts of energy pent up in various types of boilers at the instant before an explosion occurred, the Author had made no mention of boilers of the water-tube type. The following Table supplied the omission, and gave the corresponding particulars for a "Thornycroft" boiler.

Type of Boiler.	Dimensions of Boiler.		Working Pressure by Gauge.	Approximate Weight.			Available Energy.			Height to which Energy would lift Boiler.	Gunpowder Equivalent to Total Available Energy.
				Boiler.	Water.	Steam.	Water.	Steam.	Total.		
	Length Feet.	Width. Ft. Ins.	Lbs. per Sq. In.	Tons.	Tons.	Lbs.	Foot-tons.	Foot-tons.	Foot-tons.	Feet.	Lbs
"Thornycroft" water-tube .	12½	10 8	205	14·57	1·84	30·5	28,420	2,060	30,480	1,855	253

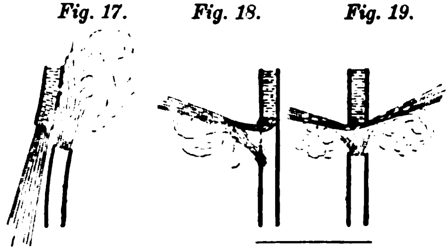
This boiler, which was of the "Daring" type, had easily generated steam during a three-hours trial for a mean I.HP. of 1,580. It was therefore of greater power than the marine boiler described in Table II,[2] and the pent up energy in the boilers of the two

[1] Mr. Longridge afterwards stated that of the eleven deaths represented by the black area in 1886 three had resulted from the explosion of the main boiler on board a tug, and eight from the explosion of a donkey-boiler on board a steamship.—SEC. INST. C.E.

[2] The heating-surface of a boiler 15 feet long and 13 feet in diameter would be between 1,940 square feet and 2,630 square feet. The surface per I.HP. in a marine boiler was usually between 2 square feet and 2½ square feet. In naval boilers, working with 2 inches of air-pressure, 1·67 square foot was given by Seaton ("Manual of Marine Engineering") as a usual allowance per I.HP.; hence the boiler in Table II would be at most equivalent to between $\frac{2{,}630}{2\cdot5}$ and $\frac{2{,}630}{1\cdot67}$, or, say, between 1,050 and 1,575 I.HP.

types if of equal power might be taken as in the ratio of 10 to 1 at least. This would be a measure of the destructive effect if each type of boiler discharged its contents in the same time—say two seconds, which would probably be sufficient for the completion of an explosion of boilers of any of the types considered by the Author. The case of a water-tube boiler was different. If every part had originally the same factor of safety, and the whole surface corroded at a uniform rate, it was obvious that if a tube $\frac{1}{8}$ inch thick had its factor of safety reduced from, say 6 to 3, the corresponding factor for the large barrels, of, say, $\frac{3}{4}$ inch thickness, would be reduced only from 6 to $5\frac{1}{2}$, and when the former were corroded quite through, the barrels would still have a factor of safety of 5. To compensate for this a larger factor of safety was provided for the thinner portion, but in any case it was most probable that when worn out a fracture would occur in a water-tube before any other part gave way. Therefore, what with older forms of boilers would have constituted an explosion had more the character of the discharge from a blow-off pipe in the case of a water-tube boiler, and the pent up energy would require minutes instead of seconds to escape; and instead of the danger to be apprehended from a marine boiler explosion being ten times as great as in the case of a Thornycroft boiler it was more probably 400 or 500 times as great. There had been no instance of a Thornycroft water-tube boiler with steel tubes having burst. There had been, however, an instance of a brass tube which had failed when plugged with wood. Mr. Wingfield.

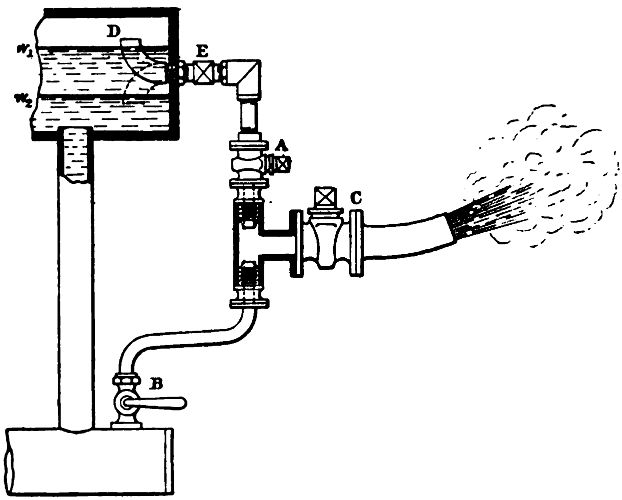
Fig. 17. *Fig. 18.* *Fig. 19.*



He had devised an experiment in order to imitate the results of an actual explosion as closely as possible with a view to determining the relative effects of different forms of fracture. *Figs. 17*, *18*, and *19*, illustrated three ways in which a tube might burst. With a tough material like steel the fracture would always, or nearly always, be like that shown in *Fig. 18*, a hole opening on one side. Brass tubes might break in any of the three ways shown, but if over-heated the fractures would probably be represented by *Figs. 17* and *19*. If the boiler was of the undrowned type introduced by Mr. Thornycroft, the upper tube would be filled with steam, and it was obvious that in *Figs. 17* and *18* the

Mr. Wingfield outflow of water would be impeded by the impact of the steam. Even with a drowned tube the two streams impeded one another, but to such a slight extent that the discharge in *Figs. 17* or *18* was but little less with this type of boiler than from that indicated in *Fig. 19*. The apparatus employed for the experiment was shown in *Fig. 20*, which represented the ends of the upper and lower barrels of a water-tube boiler. Two nozzles were opposed to each other in a T-piece of much larger section, the other branch of which represented the break. If the cocks A and C only were open the discharge from the upper tube could be measured. If

Fig. 20.



B and C only were open the discharge from the lower nozzle could be ascertained. The sum of these gave the discharge from a break such as shown in *Fig. 19*. If the three cocks were opened the jets opposed each other and the discharge under the conditions of *Figs. 17* or *18*, which were assumed to be identical in effect, could be determined. As it was of interest to compare the effects of similar accidents with drowned and undrowned tubes, the pipe D was arranged so that it could be turned to the dotted position by a spanner applied at E so that its end dipped below the water. The method of experimenting was to note the time taken to blow off sufficient steam or water to reduce the water-level from W_1 to W_2, *Fig. 20*. The reciprocal of the time so occupied was a measure (in arbitrary units) of the weight dis-

charged per second. In each case the steam-pressure was 50 lbs. per square inch. The results were as follows:— Mr. Wingfield.

Conditions of Experiment.	Time of Discharge.	Weight Discharged per Second.
	Seconds.	
Drowned Type.		
Top tube alone	23½	$\frac{1}{23\cdot 5}$
Bottom tube alone	30¼	$\frac{1}{30\cdot 25}$
Both tubes separately (*Fig. 19*)	..	$\frac{1}{13\cdot 2}$ [1]
" " simultaneously (*Figs. 17* and *18*)	14	$\frac{1}{14}$
Undrowned Type.		
Top tube alone	200	$\frac{1}{200}$
Bottom tube alone	30¼	$\frac{1}{30\cdot 25}$
Both tubes separately (*Fig. 19*)	..	$\frac{1}{26\cdot 26}$ [1]
" " simultaneously (*Figs. 17* and *18*)	35	$\frac{1}{35}$

From these figures, which were carefully checked by independent observers, it appeared that—

1. Ratio of discharges from tube broken as *Fig. 19* to discharge from tube broken as *Figs. 17* or *18* was . . . . { Drowned .. $\frac{14}{13\cdot 2} = 1\cdot 06$ to 1. Undrowned, $\frac{35}{26\cdot 26} = 1\cdot 33$ to 1.
2. Ratio of discharges from drowned and undrowned tubes, when broken as in *Fig. 19* . . . } .. $\frac{26\cdot 26}{13\cdot 2} = 1\cdot 985$ to 1.
3. Ratio of discharges from drowned and undrowned tubes, when broken as per *Figs. 17* or *18* . } .. $\frac{35}{14} = 2\cdot 5$ to 1.

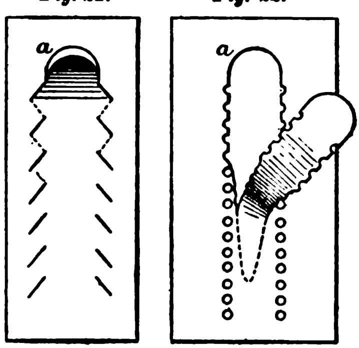
Hence an accident to a boiler with drowned water-tubes is at least between two and two and a half times as dangerous as a similar accident to a Thornycroft boiler. Previous experiments with the same apparatus, and with 25 lbs. pressure per square inch, gave practically identical results. He had referred to a case in

[1] These quantities were obtained by addition of the amounts discharged by the top and bottom tubes alone.

Mr. Wingfield. which a tube gave way. Some thin planks had been left by a careless workman in one of the wing-barrels, and floated up, closing the lower ends of several generating tubes. The circulation having been stopped, the tubes became overheated and, being of brass, one of them gave way near the bottom, relieving the pressure on the upper side of the plank, so that the water below it punched a hole of the diameter of the tube through the wood, and a mixture of steam and water at 200 lbs. per square inch pressure rushed into the fire-box. There had been, however, no disastrous results, and the first intimation which the stokers had received that their boiler had "exploded" was by a message from those on deck. The noise of the fan-blast prevented their hearing that due to the steam. This accident had occurred in the middle of a full-speed run when the fires were being urged to their utmost.

It had been mentioned by the Author on page 156 that the secondary rents do not always follow the seams of rivets or lines of natural weakness. Before rupture the greatest stress would probably be in the line of least section. After rupture commenced, however, the rush of water and steam forced back such a flap as that shown in *Fig. 1* in a direction more or less normal to the plate. Under these conditions the greatest stress was no longer necessarily along the line of least section, and this he proceeded to illustrate by tearing a strip from a perforated sheet of paper, where the line of rupture proved to be in the direction shown by dotted lines in *Fig. 22.*[1] He did not suggest that, in a boiler explosion, the secondary fractures always converged, but he merely wished to point out that when the tearing force acted normally to the plate the line of greatest stress was not likely to be in the line of what the Author had called "natural weakness."

Fig. 21. *Fig. 22.*



[1] It was a matter of common observation that when it was attempted to remove a newspaper wrapper by tearing off a narrow strip of paper the lines of rupture converged, and the strip often came off before the wrapper was torn quite across. A method had been devised of perforating the wrapper as shown in *Fig. 21*, so that when the top was pulled the lines of fracture shown in dotted lines began to converge, but were immediately widened by the next pair of slits, and so on until the entire strip was torn cleanly out of the wrapper.

Mr Wingfield.

The opinion had been expressed by the Author that, since a good deal of the grooving to which boilers were sometimes subject took place in the steam-space, it could not be so much due to chemical as to mechanical action, and local strains due to sudden changes of section. He agreed with the Author's conclusion, but he considered the implied assumption that chemical action could occur but slightly in steam-space was erroneous. There were many instances in which the plates had been considerably corroded in the steam-space of boilers, and Professor Lewes had investigated the kindred case of the excessive corrosion of those plates of a hull which happened to be near the boilers[1] and had proved experimentally that, of two steel wires dipping in sea-water, the chemical action on one, which was kept in a current of hot moist air, rendered it strongly electropositive to the other. There could be little doubt that a similar chemical action would sometimes take place in hot moist steam.

The grooving from mechanical action, on which the Author rightly laid great stress, was also met with in propeller shafts.[2] In boilers the sudden change of stiffness near a joint enabled the metal at that point to become sufficiently "fatigued" to give way and form a crack under repeated stress. In propeller shafts the section was nearly uniform, and as these sudden changes of stress did not occur, the groove had to be started in some other way. The necessary cause was found in galvanic action between the steel shaft and the brass sleeves which formed the shaft journals in the stern-tube. A shallow groove was first formed by corrosion; the stress at the bottom being greater than at the sides of the groove, the latter quickly deepened from giving way under "fatigue." Cracks often attained a depth of several inches before showing more than a scratch at the bottom of the original groove. That this was a correct explanation appeared from the fact that if local galvanic action was prevented by covering the shaft with india-rubber, or by serving it near the brass sleeves with a few turns of marline, the cracks were prevented.

Proper arrangements of internal feed-pipes deserved more attention than they had received. It did not appear to be generally known that feed-water (containing air as it generally did) had a rapid corrosive effect if it impinged on hot boiler-plates. Discharging feed-water into the steam-space, as was sometimes done, was of more than doubtful benefit. He had known cases of priming

---

[1] *Engineering*, vol. lii. p. 575, and lviii. p. 399.
[2] *Ibid*, vol. lvii., 1894, p. 464.

Mr. Wingfield. produced by such an arrangement, owing to sudden condensation of steam, and consequently increased ebullition. This condensation appeared to have occurred in the case described on page 167, where the pressure was reduced by turning on the feed.

Mr. Head Mr. JEREMIAH HEAD remarked, with regard to external corrosion, that where there were no leakages there was usually no corrosion. But if a boiler were out of use and exposed to the weather, external corrosion made steady and rapid progress. In a boiler in regular use, external corrosion was always due to leakage, or to the dripping of water upon some portion of it from a roof or steam-pipe, or to some damp material, such as lime or brickwork, being in contact with it and acting like a sponge. Alternate wetness and dryness was the worst enemy to boiler-plates, as it was to timber. The internal shells of boilers seemed also impervious to corrosion under ordinary circumstances. He had measured the thickness of a boiler shell which had been in use for fifteen years without detecting any diminution. Corrosion must therefore be regarded as an evil due to local circumstances. A very unfavourable condition was presented by steam and water alternately playing on one side of a plate, whilst the products of combustion were in contact with the other. This occurred to uptakes passing through steam-spaces. Boilers such as that shown in *Fig. 5* soon failed in the uptake, the portion of which between the high- and low-water level, being exposed to continuous splashing, wasted very rapidly by pitting. The uptake had usually to be renewed long before the boiler was worn out. Probably this was due to the action of the highly heated iron upon the steam, whereby some of it was decomposed, forming oxide of iron and setting free hydrogen. For the avoidance of internal corrosion it was of advantage to feed the boiler with water containing a small quantity of calcium carbonate which was deposited on the internal surfaces and formed a protective coating. He believed that it was customary to coat the internal surfaces of marine boilers with a wash of cement and water, and that this was found very efficacious in preventing corrosion. He considered that the most mysterious cases of internal corrosion were those due to scoring or grooving. No doubt, the breathing action of circular end-plates, and the tendency of the longitudinal lap-joints of cylindrical boilers to pull into a true circle were the primary causes. In the latter case he thought the remedy was to avoid lap-joints under such circumstances, and to use butt-joints and cover-plates. With the very high pressures now in use, all vessels made to withstand them should be of such form that no smaller pressure than the bursting-pressure could alter their form.

Mr. Head.

With regard to strengthening flues by tee-bar rings in the water-space, which had been suggested, he disapproved of such expedients. The rings remained steadily at the temperature of the water, whereas the flue itself varied between that and the temperature of the products of combustion. On that account it required more space for expansion and contraction than the rings would allow of, so that it became compressed or "jumped up," and in contracting was held back by the ring, and was sure eventually to relieve itself by developing longitudinal cracks. He had seen boilers attached to blast-furnaces in Lincolnshire supported in the manner shown in *Fig. 3*. The feet, however, were generally higher up, and set on the top of and not inside the brickwork. Boilers fired with gas under those circumstances could not be very dangerous, as they lasted for long periods. He knew of one case where the boilers were thirty years old, and where, after having served about twenty years, the feet had been reversed, the mounting taken from the top and put on the bottom, and the boiler turned round to start anew. This had been done four or five years ago, and so far as he knew the boilers were still working. Some thirty years ago it was the custom in the Cleveland district to use in connection with the blast furnaces plain cylindrical boilers 80 feet long by about 4 feet in diameter. They were continually failing, owing to seam-rips, which invariably started on the under side. After a certain explosion he had made a careful examination of some of these boilers which were still working. They were suspended from four cross girders. He had found that when the boilers were at work, the nuts of the suspension bolts at the two ends were slack, and when not at work those at the two middle girders were slack. The slackness amounted in some cases to a gap of as much as ½ inch. This proved that there were alternately compression and extension stresses at the bottom of the boiler of a very severe character, and these, no doubt, led to the seam-rips. Similar boilers over which he had had control were afterwards suspended upon volute springs, which enabled them to expand and contract without setting up any destructive stresses, and no seam-rips had occurred in them. He did not think *Figs. 8* gave a good representation of the Rastrick boiler, but he agreed with the Author that the Rastrick, although of a type common in Staffordshire and in the north of England, was a very bad boiler. By the gradual supersession of wrought-iron by steel it was becoming obsolete, because, in steel-works steam was in almost all cases raised in Lancashire boilers, working at a very much higher pressure than the old ones. The Rastrick boilers generally worked at a pressure

Mr. Head. of between 30 and 40 lbs. per square inch. They were usually defended at the bottom, where they were struck by the flame, with a little brickwork, because it was at this place that the boiler was most apt to deteriorate and become thinner. One great disadvantage of such boilers was that they were surrounded with brickwork, and were placed where the men were working, so that if they did explode every brick became a bullet, and this was the reason why the consequences were often so disastrous. They were also of large diameter, and the flame being external as well as internal, and hidden from view by the brickwork, deterioration could proceed on the outside to a very great extent without being easily discerned. They had some advantages, one being that they held a considerable quantity of water, and so kept the steam-supply very equable. Where there were a number of boilers and a large range of steam-pipes, steam being drawn off from a great number of engines, it was important that there should be a number of bodies of water like that which kept the steam constant, and acted, in fact, like a fly-wheel. He thought the man who riveted the holes in *Fig 14* deserved the very worst penalty that the law could enforce.

Mr. Beaumont. Mr. W. Worby Beaumont observed that the Author had assumed that a great deal resulted from variations in steam-pressure, but he had not defined the causes to which the actual stresses were due. The variations in pressure in locomotive boilers had been particularly mentioned by the Author, but he desired to know under what circumstances those great and sudden variations occurred to such an extent as to cause those stresses in the boiler to which he appealed as the causes of grooving. The breathing of boilers and its effect on certain parts had also been referred to by the Author, who had mentioned it in one place as one of the causes, at all events, of the aggravation of the grooving, while in another place he rightly showed that it was necessary, in certain of the boilers described, that the breathing action should be carefully allowed for. He referred to the occurrence of grooving where bending had caused the material to be under tensile stress, and also to the fact that these tensile stresses occurred in several places not mentioned in the Paper, but in which it was evident they might occur, owing to unbalanced areas. In *Figs. 8*, it would be seen that in consequence of the unbalanced area in the vertical internal tube, there was an unbalanced pressure of about 20 tons upon the central piece. It was impossible that that could be existing, and from time to time diminishing to nearly nothing, as from day

Mr. Beaumont.

pressure to no pressure at night, without having considerable effect in varying the mechanical stresses, not only on the part of the boiler carrying that flue at the bottom but on the horizontal flue also. Again it would be seen with regard to *Figs. 5* that there was a great difference in the areas upon which the pressure was being exerted. The uptake had not given way in the example, as the Author had said, but the angle-ring connecting it to the fire-box had given way. Again, the stresses in the part in which the groove occurred were of a tensile character. Some time ago he had suggested to Mr. Thomas Andrews, who was proposing to make experiments on the relative corrosion of materials which had and had not been under stress, that it would be interesting to ascertain what would be the difference in the rate of the corrosion on specimens under and not under stress during experiment. Experiments had been made by Mr. Andrews,[1] although not in the manner suggested, and he had found that the difference was either nearly if not quite inappreciable. He had simply bent the specimens, immersed them in a saline electrolyte and passed a small current through them so as to encourage the corrosion. By simply bending a piece in that way and allowing it to return as far as the unsatisfied stresses would take it, the greater part of the stress would be eliminated and the conditions would be very different from those which would obtain in a boiler as in either of the cases referred to. In the case, for example, of the bottom of the uptake in the vertical boiler, while on the one hand there was the pressure on all but a small area in the upper part of the boiler tending to force the whole upwards, only part of that pressure was balanced by that on the top of the fire-box. There was also the change in the length of the fire-box due to the increase in temperature of the sides, and an almost equal increase in the uptake-pipe, so that there were two different stresses both tending to bend the angle-bar and to open it in the re-entrant angle, producing a tensile stress. The same thing occurred in many cases, and it would appear that corrosion did take place more rapidly, whether in steam or water, in those parts of a piece of iron under stress where the stress was great and where it was local, and of a tensile character, as in that angle-bar. Almost all the grooving, whether in the locomotive furnace boiler or in any other, took place in this way, and in places where the local stress was of that particular kind. In his reply, those points would probably be referred to by the Author, as well as the way

[1] Minutes of Proceedings, vol. cxviii. p. 356.

Mr. Beaumont. in which stresses were supposed to occur, not simply by changes of the pressure of steam, but the changes of temperature, producing the "curling up" at the ends of the boiler, which of course meant that the whole boiler was changed in form to a certain extent. In a great many cases it would no doubt be difficult to show that stresses of a measurable kind occurred in consequence of the change of form, because the change in temperature was such that the change in form might occur without bringing about any very great stress on the material.

Mr. Moberly. Mr. C. H. MOBERLY said that the Author appeared to ascribe the grooving in the ends of boilers to the change of steam-pressure and consequent temperature. He thought that the steam-pressure affected it much less than the changes of temperature in the furnace, and the varying expansion of different parts of the boiler in consequence of different temperatures to which it was exposed. That appeared to be the real difficulty in dealing with the flat ends of boilers. The grooving referred to might be partly due to pressure, but he considered it was also due to changes of temperature. Certainly in Cornish and Lancashire boilers the effect of changes of temperature in the flue was extremely important, so much so that pressure might be almost disregarded. It was prevented by providing sufficient movement in the ends of the boilers, to allow changes of form to take place without doing any harm. The top of the boiler was almost always hotter than the bottom, whilst the top of the flue was at the highest temperature of all. There was always hogging of the flue, which was measurable and must produce serious effects on the ends of the boiler, and if these were too rigidly stayed or were too thick and flat, a great deal of mischief would result. He asked for details of the construction of the boilers referred to in *Figs. 9*, *10* and *11*, and he would be glad also to know the proportioning of the rivets. *Fig. 9* illustrated a most extraordinary specimen, and some further information concerning it would be interesting.

Mr. Wolfe Barry. Mr. J. WOLFE BARRY, Vice-President, suggested that the Author should give the ordinary working-pressure in tons to the square inch in the case of boilers that had exploded, and also the estimated pressure per square inch at the moment of explosion. He understood the Author to state that in one case the mean circumferential stress was about 8·6 tons per square inch, whereas the material was capable of withstanding a stress of 20·6 tons. He did not know whether those calculations took into account the abstraction by rivet-holes, and represented the greatest possible stress at any particular place. A working strain of 8·6 tons on

Mr. Wolfe Barry.

a material capable of bearing 20·6 tons per square inch was a large amount of strain to which such materials should be constantly exposed. It was contrary to experience in bridge-building, and it would be interesting to know what the strains usually were as compared with the ultimate strength of the material in boilers such as had been described.

Mr. Fowler.

Mr. W. H. Fowler said in reply that he quite endorsed Mr. Longridge's opinion with reference to the application of the hydraulic test. There was no doubt that the application of that test without taking suitable gaugings was probably in many cases productive of more harm than good. As to the necessity for compulsory inspection, and further legislation, he thought that the death-rate from boiler explosions had now been happily reduced to such insignificant dimensions in this country that any further steps in that direction were uncalled for. The case had not been overstated by Mr. Longridge as regarded the comparatively insignificant danger that arose to human life in this country on that score. As compared with America, for example, he believed that more persons were killed and injured from explosions in that country in the course of a month than were killed and injured in this country in the course of two or three years. It would be observed from *Fig. 16*, that the death-rate had largely diminished since the introduction of the Boiler Explosions Act. He had no doubt that that reduction was due to the operation of the Act, coupled as it had been with the salutary action of the Board of Trade in holding their enquiries, and occasionally appointing some of a formal character which had brought home the responsibility to boiler-owners more forcibly, and had served to emphasize the recommendations that the various inspecting and insurance companies had made from time to time, but which, prior to the passing of that Act, had had very little chance of being adopted. The owners of boilers had formerly postponed repairs as long as possible, and, in the event of a boiler bursting without causing injury to life, no inquiry followed, whereas, at present, whether there were injuries or not, there was the salutary fear of a public enquiry. In reply to Mr. West, marine-boiler explosions had not been extensively dealt with in the Paper, chiefly because there were few marine-boiler explosions to deal with, which was no doubt due to the better design of such boilers, and to the superior supervision and control which regulated them. The energy of explosions had been referred to by Mr. Wingfield. The destructive character of an explosion did not necessarily depend upon the amount of

Mr Fowler. energy contained within the boiler, but upon the manner in which that energy was liberated. If a blow-off tap were opened the energy would be spent in course of time, but in such a case the liberation would not be attended with injury either to persons or property; but, on the other hand, if the same energy were suddenly liberated by ripping a portion of the boiler shell it might be very destructive, and not only lead to the expending of a large amount of energy in consequence of the liberation of the steam and water, but probably to the liberation of a large potential energy in the form of buildings, etc. With reference to the lines of rent to which Mr. Wingfield had referred, these must follow in any case the lines of least resistance. But many complex matters were more or less involved, so that it was impossible to predict how the lines of rent would travel. No doubt the stresses, when a rent was started, imposed on the material at the ends of such rupture were capable in many instances of producing very complicated effects. With regard to corrosion in the steam-space, Mr. Wingfield seemed to think, from his remarks as to the cases of grooving, that he (the Author) did not consider corrosion in the steam-space could take place. That was an opinion which he would not like to endorse. He was about to say that experience showed that corrosion actually occurred in the steam-space; and he did not wish that that impression should be conveyed by his Paper. Of course it was in the water-space principally that corrosion of the most serious amount occurred. With reference to those cases of grooving to which he had alluded, in the majority the sides of the groove formed an angle of about 90°; it was in reality an open furrow; but in those special cases which had occurred on the North Eastern Railway the grooves were so fine that it would have been impossible to have discovered them by inspection. In fact, he knew of one particular case, in which a locomotive superintendent had been so much impressed by the knife-like character of the groove that he had caused the barrel to be cut open, and the plate bent back, and it was only in that way that the existence of the groove had been discovered. The boiler had been of Low-moor iron, and subsequent tests of the material went to show that the material was of good quality. It might, of course, have been thought that the grooving had been started by a caulking-tool on the inside in the first instance, but there had been absolutely no trace of any such action having been produced; and, moreover, it was not the practice at the boiler-shop to caulk the inside of the longitudinal laps. Egg-ended boilers had been referred to by

Mr. Head, who had said that they were not generally set in the manner shown in the Paper. He was happy to say they were not, but that was simply quoted as an illustration of the ignorance occasionally displayed; and he was sorry to say that engineers sometimes resorted to broad seatings, and an amount of brickwork which was absolutely unnecessary; one object he had in calling attention to them was to point out that the bearing-surface of a boiler did not require to be wide—3 or 4 inches was always sufficient to carry the weight, and that at the same time could be so arranged as not to interfere with the inspection, or afford a lodgment for moisture. The distribution of stress in a steam-boiler was a matter which must be largely decided by experience, and could not often be determined by pure mathematics. The plain egg-ended boiler, for instance, was mathematically twice as strong at the circumferential seams as at the longitudinal seams, and yet those boilers, often suddenly ripped in two at the ring-seam of rivets, where they ought to be twice as strong as at the longitudinal seam, and time after time compound explosions had been recorded in which a slight shock arising in one boiler had sufficed to start off the group and cause them to rip in this manner. A striking illustration of that had been afforded by a remarkable compound boiler-explosion that had occurred some little time ago at Shamokin, in America. There had been a group of thirty-six boilers, and the explosion of one boiler in the group appeared to have started off another twenty-six. He had recently received photographs of that explosion, and it was remarkable that in nearly every case the rents had taken place at the ring-seams, where they ought, he supposed, according to mathematics, to have been stronger. It was only another illustration of what every engineer knew—that when mathematics came to be applied to engineering structures it needed to be tempered with a good deal of common sense and actual experience. It had been asked by Mr. Beaumont when the variations in pressure in locomotives occurred which were referred to as one of the causes of the grooving described, and what was the magnitude of the actual stresses thus set up. In reply to the first of these questions, it was only necessary to consider what took place when a heavily laden goods train came to a steep gradient, and afterwards ran down an incline. Large fluctuations in pressure were well known to engine-drivers from that and other causes. These fluctuations in pressure were necessarily followed by variations in the intensity of the bending stress which occurred at the longitudinal joints when they were of overlap form. What was their Mr. Fowler.

Mr. Fowler. precise magnitude it was of course impossible to say; but the grooving itself afforded irrefutable evidence of their existence. Mr. Beaumont had also said that the grooves seemed always to occur when bending had put the material under tensile stress. That, however, was not the case. The stresses which set up the grooving were sometimes alternately compressive and tensile. It was, in fact, the variation in intensity which fretted and deteriorated the material locally. With regard to the stresses to which Mr. Barry had referred, he was discussing the effect of cutting large openings in boiler shells, and he somewhat regretted that that matter had not been dealt with a little more fully. What he meant was, if the calculated stress in a length of the shell equal to the diameter of the manhole, arising from the bursting-pressure were divided over the remainder of the shell in a line passing longitudinally through that diameter, it would only give a stress of 8·6 tons per square inch, whereas, as a matter of fact, the shell had burst, the plates of which that shell was made having been proved subsequently to be capable of bearing a stress of 20·6 tons. His remarks went to show that the distribution of the stress was very irregular, and that close to any large hole there was a very great stress. What the magnitude of that was it was difficult to say, and respecting those manholes he wished to point out that the distribution of the compensating ring was a matter of great importance, as well as the mere quantity of material that was allowed. For instance, had the material in the neck, shown in *Fig. 11*, been crushed down into a flat ring on each side of that opening he had no doubt the shell would not have failed at that particular pressure. The distribution of material was such as really to afford very little help to the part of the boiler-shell immediately surrounding the hole.

Correspondence.

Dr. Emery. Dr. C. E. Emery considered that the Paper clearly and concisely pointed out the principal causes of boiler explosions, and embodied a number of interesting illustrations based on several types of boilers employed in Great Britain. In the United States there had been explosions from similar causes, but few failures had resulted from distortion of the plates, for the reason that the system of internal bracing was in general more thoroughly carried out in detail. When the country had been undeveloped, and iron more expensive, and there had been limited facilities for dealing with heavy plates, it had been exceptional to find plates thicker

than $\frac{5}{16}$ inch about the furnaces and connections, or even in the flat external heads of a boiler, though circular shells had, of course, been proportioned to the strain. The thin plates required necessarily many braces, and although boilers had in some respects grown to be more massive in construction, heavier plates being used even where unnecessary for strength, but simply to provide for corrosion, the system of bracing had been to a large extent continued; and in many cases, although the points of bracing could safely be separated, small difference had been made in practice. In fact, return-tubular boilers with circular shells at the rear, but with fully braced furnaces in a fire-box externally shaped like that of a locomotive boiler, were still extensively used in small harbour vessels and in larger vessels on fresh-water lakes for steam-pressures up to 100 lbs. per square inch. Dr. Emery.

Again, in the United States few large flues which were subjected to external pressure were constructed without bracing. Circular furnaces stiffened by flanges and corrugations were employed, as a rule, only for marine boilers, and even in circular vertical boilers the inner and outer walls were almost universally braced by stays or screw-sockets as if they had been flat surfaces. In this way thinner fire-plates were used than were possible by the other system, and collapses of such furnaces were unknown. Again, globular ends were used to a smaller extent under compression, as they were not needed except in new forms of boilers rarely duplicated. As a rule, vertical boilers had tubes through the crown-sheet which acted as braces and tied the crown-sheet and the boiler-head together. It was never attempted in America to dispense with the bracing on a comparatively flat head by constructing the boiler of thicker material. The predominating type of land boiler was a simple horizontal cylinder with fire-tubes running the whole length of the lower part of the shell, and with the flat end-plates above the tubes supported by diagonal braces running to the shell at an angle rarely greater than 30° with the axis of the boiler. This system had given no trouble when the braces had been riveted in place through proper ends, as was the general practice, but boilers in which fewer braces had been attached through stiffening angles had in some instances failed.

Angle-bar connections between the heads and shells of boilers, or at the junction of the boiler-shells and drums or flues like those shown in *Figs. 4, 5, 12, 13* and *14*, were practically unknown in the United States. The boiler-head was always flanged to enter the shell, and in applying a drum to a boiler the bottom of the drum was flanged outwards, as in *Fig. 11*, but the flange was

Dr. Emery. made wider and double-riveted to the shell, thereby stiffening the junction and relieving some of the strain incident to a connecting drum as pointed out in the Paper. It was common also to leave the boiler-shell intact beneath the connecting-drum, with the exception of small drain-holes and one larger opening to give access from the drum to the boiler. This latter feature was not a perfect remedy, but showed that weakness at such points had long been known and in a measure provided for. He had always made it a point to insert special braces across such openings, as a little consideration would show that as soon as an opening was cut in a shell for a drum, the balancing pressure parallel to the axis of the drum was furnished by transmitting the pressure on the head through its shell to the boiler-shell, but the component at right angles to it was in no way provided for without distortion unless braces were inserted across the opening, though the heavy flanges referred to, or, in case of a manhole opening, the heavy covering-plate, added some strength. His practice, in the case of a manhole, was always to set the narrow axis longitudinally to the shell, and then to rivet to the outside of the shell a heavy wrought-iron ring, with its outside curved to fit the shell and the inside flat for the joint, so that the greatest thickness of the ring was at the place where it was most needed.

Failures had frequently resulted with thin plates from the consideration that curved surfaces needed no bracing. A curved surface merely transferred the strains imparted to it to the ends of the arcs. If they were not met at those points by resistances equal and opposite, such as would be provided by well-arranged braces equivalent to plates continuing the curved surface, the structure would, at the haunches of the arches, necessarily be out of equilibrium, and would move until the distortion threw the strain upon other parts sufficiently strong to withstand it. For instance, in a wagon-top boiler with internal furnaces, having semi-cylindrical tops and water-legs or water bottoms, the curved tops of the furnaces transmitted the compression to the ends of the arcs; but the pressure tended to force the furnaces as a whole away from the top of the boiler. Such furnaces must therefore be braced to the circular shell above to the same extent as for flat surfaces, that is, in equal horizontal spaces, rather than those measured on the circumference; or the haunches of the arch must be supported by larger braces up to the shell, and the strain from such large braces distributed to the shell by a network of diagonals. Furnaces had been liable to leak at different points from neglect of this principle, and ruptures might have been due to this

cause. Some dangerous explosions had occurred to boilers of this type, in which the rupture had started on the sides near the junction of the upper circular shell with the flat side plates, showing clearly that the cross-bracing, which was perfectly afforded at the bottom by socket-bolts between the furnace and the shell, must be supplemented by cross-braces above the furnace with branched ends extended somewhat above the horizontal diameter of the upper shell. Some failures had resulted from neglect of this principle in vertical boilers. Referring to *Figs. 5* and *13*, it would be seen that, although the crown of the furnace was supported at the centre by the tube, a great portion of the aggregate pressure was transferred by the globular shape to the edges. This downward force could only be met by the corresponding upward force due to the aggregate pressure on the boiler-head above. The force was therefore transmitted downward through the shell of the furnace and the bent flange connection to the plates of the main shell, and upward through them to the boiler-head. If the shell of the furnace and that of the boiler were connected by socket-bolts, as in American practice, no strain would be brought upon the joint at the bottom, but without this there would be considerable bending strain on the annular bottom of the water-leg, particularly for a wide water-space. In a particular boiler of this kind, without the central flue, the crown-sheet of the furnace was of greater diameter than the shell, but was connected to the latter, forming an annular recess from which fire-tubes were run downward in the water-space of the legs. No stay-bolts for the furnace were used in this case, and the inventor supposed that the globular crown-sheet rendered vertical bracing unnecessary. A boiler of this type had exploded, and from leakages that had been reported on the others and the method of failure, Dr. Emery concluded that the difficulty was started in the flat annular surfaces through which the downward forces from the furnace crown were transmitted to and balanced by the upward forces from the head of the boiler. Dr. Emery.

The failure of a standpipe or water-column of a waterworks could be traced to the same principle. The standpipe was of large diameter for a limited height, to provide storage for ordinary purposes; but the diameter was reduced above like a bottle, or like the furnace and attached smoke flue shown in *Fig. 13*, discarding the outer shell; and the neck extended up 100 feet or more, so that, in case of fire, the pumps could be started more rapidly and a higher pressure secured promptly. The comparatively flat surface around the neck had been strength-

Dr. Emery. ened by a few braces, probably in order to keep the structure in shape and to provide for wind strains, rather than from any complete idea of the hydrostatic principles involved, but the entire bottom had been practically flat, being only stiffened by angle-iron to keep it in shape. This structure had been perfectly stable so long as the water-level was kept below the neck, and it would have been stable for any height of the large column had there been no neck; but when it had been attempted to fill the standpipe to a considerable height above the neck, a rupture had taken place, and the standpipe had fallen and been destroyed, evidently for the reason that the upward pressure on the neck had been sufficient to bend upward the outer portion of the bottom. Only the portion of the bottom equal to and opposite the central pipe had been in equilibrium for the full pressure. The upward lift on the neck due to the higher column had been resisted entirely by the weight of the metal in the pipe, in addition to the forces due to such portion of the weight of the water as could be transferred through the flat bottom to the shell at its edges, so the shell had risen, the bottom had bulged and the whole weight of the column and its contents had been thrown on the rounded end until the pressure had torn the bottom out of the shell and caused the destruction of the structure.

Mr. Isherwood. Mr. B. F. Isherwood, Chief Engineer, United States Navy, remarked that when the explosions of steam-boilers first attracted attention they had been attributed to several imaginative causes, all of which had been based on a supposed sudden and mysterious creation of enormous pressure, akin to the explosion of gunpowder, in the boiler, which no strength of material, propriety of design, or skill of execution, could withstand. Had any of the causes assigned been true, boiler explosions, instead of being the rarity they were, considered with reference to the number of boilers in use, would have been of such common occurrence and so difficult to guard against by any precautions, that the use of steam-power would have had to be abandoned. Instead of this, explosions of boilers, never frequent, had become rarer and rarer by the employment of persons whose intelligence and incessant watchfulness were sufficient to maintain the conditions essential to safety, and needed never occur with any boilers however designed or manufactured, if they were tested at intervals of, say, six months with a pressure of between double and quadruple the pressure to be employed, and if such working-pressure were not exceeded. If, in addition, the proper water-level was maintained in the boiler, no injury of any kind would be sustained by it. A pressure test and

an examination of any boiler every six months by a competent engineer, combined with the application to it of any of the "pop" safety-valves, the weighting of which could not be tampered with, and supplemented by a careful watching of the "feed" by a reliable attendant, would ensure almost absolute immunity from danger, let the material, design, and workmanship of the boiler be what they might. No other precaution was needed, and none other would be of any avail in their absence. Mr Isherwood.

However faulty might be the design and construction of any boiler, and however inferior its material in tensile strength, if it satisfactorily withstood a test-pressure of between two and four times the pressure under which it was used, it would not explode unless the prescribed working-pressure was sufficiently exceeded. And no matter how great the deterioration of the boiler might be from six months to six months, if it bore the test it would be still strong enough for safety. When it showed signs of yielding under the test the working-pressure must be reduced until the multiple test-pressure could be borne. It was important that the test-pressure should be maintained within the boiler for, say, at least between fifteen and thirty minutes, instead of being released the moment it was reached. A boiler might sustain the momentary pressure and yet yield under the prolonged pressure. The cause was the ductility of the metal of which the boiler was constructed. To stretch the metal was to do work upon it in the way of increasing its length and correspondingly diminishing its cross section which required time, and these processes might be slow or rapid according to conditions, but under all circumstances time was required, which was often considerable if the resisting and the stretching forces were nearly equal. As the stretching proceeded, the metal in the cylindrical shell of a boiler, for example, became thinner and thinner, until it ruptured at last under the stress it had borne at first, without elongation. In an important explosion experiment made many years ago at Sandy Hook, on a large boiler with a rectangular internally-fired shell, by Mr. F. B. Stevens, of Hoboken, the metal of several seams, after a terrific explosion which entirely destroyed the boiler, had been found to be in as good a condition as before the explosion. The rivets and rivet-holes had been intact and quite uninjured, and no metal forming part of the seam had been ruptured. The two plates united by the seam had been, however, entirely separated, some of the rivets sticking into one plate and some into the other, although the rivet-heads had not even been bruised, and the rivets not even bent. The metal of the plates at the seam had stretched

Mr. Isherwood. so much under the stress, without rupture, that the rivet-heads had slipped uninjured through the rivet-holes, which had been sufficiently enlarged by the stretching to pass the rivet-heads, the holes recovering their normal diameter by the elasticity of the metal as soon as the stress ceased.

Elasticity was the first quality of any boiler material, and without it the construction of boilers would be impossible. The strain, notwithstanding that the stress was equal and simultaneously applied in a boiler, was necessarily unequal, some parts having more and some less thrown upon them than intended, by reason of the different rigidities of different pieces of metal, and because parts of the boiler were left under greater tension due to difference of treatment during manufacture than other parts, whereas this kind of tension should be the same for all parts. For example, no two braces or socket-bolts connecting opposite flat plates in a boiler ever had the same tension upon them when the boiler was free of steam- or water-pressure. One brace might be quite slack and the adjacent braces very taut, the latter having to bear more than their share of the strain, and to stretch considerably before the slack braces could be brought into action and made to contribute their share of strength. All other parts of a boiler showed similar inequalities of strain and strength. Only the elasticity of the metal afforded a compensation which at last brought all the parts into action, and enabled a boiler to be worked with safety.

A boiler explosion, in the proper sense of that phrase and distinguished from a boiler rupture, depended on two conditions only, namely, the rapid or slow increase of pressure by means of an elastic fluid beyond the strength of the boiler to sustain it, and the simultaneous yielding of a considerable portion of the boiler shell. There could be no yielding of the shell unless it was too weak to sustain the pressure within it; but if the portion that yielded was sufficiently small, there would only be a rupture of the shell but no explosion. The damage would be local, not general, and the destructiveness of an explosion, other things being equal, would be largely in proportion to the extent of the portions of the shell which simultaneously yielded. The pressure of explosion must be produced by an elastic fluid capable of continuing its action by its expansion after the actual rent in the shell had occurred. A bursting pressure produced by an inelastic fluid, a liquid like water, caused only a rupture of the boiler but not an explosion. This was an important distinction. With the pressure in proper subordination to the strength, the weak

boiler was no more liable to explode than the strong one. The only efficacious means, therefore, for the prevention of boiler explosions, were those which ensured that the working steam-pressure should never exceed a certain fraction of the water-test-pressure. As long as that was done there would be no explosions. This immunity from over-pressure could be automatically secured by means of a conical-faced valve which would open, at the pressure to which it was set, instantly to a height that would discharge all the steam the pipe could pass at the given pressure, and would remain open as long as the pressure to which it was set was beneath it. If the area of the pipe were such that it could pass the bulk of the steam that could be obtained at the boiler-pressure by the maximum rate of combustion of the fuel, and if the valve, or the valve-seat, were made of a material which would not adhere or "stick," and if, finally, the valve were placed in a locked box so that it could not be tampered with by the boiler attendant, the means evidently would be complete to render an explosion next to impossible. No common safety-valve could meet these requirements. It would, indeed, open at the pressure to which it was set, but it would not open wide enough to discharge nearly as much steam as the connecting-pipe could pass, so that the boiler-pressure would continue to increase above the limit to which the valve was set. The conditions were, however, met by the "pop" safety-valve, with nickel-plated seat to prevent sticking, of which there were many varieties differing only in details. Such a valve opened at the pressure to which it was set and instantly rose to the height needed for the discharge of all the steam at the boiler-pressure which the connecting pipe could pass, and remained there until the pressure fell, when it closed with but 1 lb. or 2 lbs. per square inch less pressure than the opening pressure. The pressure beneath the "pop" valve for the aggregate of its area when lifted, was a little more than the pressure beneath it for the whole of its area when seated; the two pressures per square inch for the areas of the lifted and of the seated valve being inversely as those areas. Mr. Isherwood.

The only manner in which deficiency of water in a boiler could produce rupture or explosion was by the softening of the metal which took place when denuded of water it was exposed to the high temperature of the gases of combustion, whereby its strength was so much reduced that it yielded to the pressure which it had previously withstood. Up to a temperature of about 550° F., the strength of iron and steel slightly increased, but then, as the temperature rose, it rapidly decreased. The specific heat of iron

Mr. Isherwood. and steel also increased rapidly with increase of temperature. On admitting water to a boiler having part of its heating-surface overheated to a greater or less degree owing to absence of water, the water took up the heat from the metal, and the quantity of heat thus absorbed was measured in Fahrenheit units by the product of the number of lbs. of overheated metal cooled into the number of Fahrenheit degrees between its overheated and cooled temperatures, and the mean specific heat of the metal between those temperatures. No steam could be generated from the water admitted until the water had absorbed the number of Fahrenheit units of heat required to raise it from its initial temperature to its temperature under the boiler-pressure; nor until the specific heat of the water was so much greater than the specific heat of the metal, about seven times for high temperatures, that the metal would not furnish heat enough while cooling to produce any steam, so that the steam-pressure would rather fall in the boiler instead of rise by the admission of cold water. To produce a boiler explosion, the statical pressure of the steam within must alone produce the first rent in the shell, and that rent must be comparatively large and made with great suddenness. The other causes were secondary to the first, namely, the effects of steam-room and water-room, producing duration of the steam-pressure upon the moving mass, and thus aggravating its destructive power. An exploded boiler, as soon as a rent was made in the shell, constituted a large rocket, and all the phenomena connected with it could be explained by the application of the laws of natural philosophy. There was nothing mysterious in even the worst cases of boiler explosions; they were all due to the same mechanical causes, and followed the same mechanical laws. They involved nothing that could not be provided against by the precautions recommended if honestly executed.

Mr. Marten. Mr. E. B. Marten considered that the figures given in the Paper, as to the energy stored up in the hot water, were truly described as the only satisfactory basis for investigation of the subject. They were perhaps with difficulty realised by those who had the care of boilers. It had been necessary to take some pains to explain the matter to juries at inquests or to others investigating explosions, and the simple illustration seemed best understood, that the boiler would have kept the works going for a considerable time if the energy had been used properly through the engine, but as it was let loose suddenly it spent its force in destroying the premises. The true and simple causes of boiler explosions, as elucidated by the careful study of their records for a long period, were still

tardily accepted by those who had charge of boilers; and mysterious forces, among which electricity was a favourite, because some explosions had happened during thunderstorms, were still put forward to account for them. In a series of models of boiler explosions which had been exhibited in various centres of industry, a hydro-electric boiler had been shown to explain that its electricity was only due to the friction of the partially condensed steam in passing through a wooden orifice, but he feared that when the boiler was seen to emit brilliant sparks from every part, the idea of electricity being a cause of explosion had been rather strengthened than dispelled. Mr. Marten.

All who had had the care of boiler-inspection on a large scale must have been surprised that some boilers which had been found to be very defective could have worked at all, while others that appeared sound had exploded. As an instance, an old Rastrick boiler had been found to be reduced in places to the thickness of a sixpence, and another had been substituted 2 feet smaller in diameter and working at 20 lbs. per square inch less pressure, and yet the new boiler had burst in a short time and caused much damage. The owner had been much puzzled, as the old boiler had worked safely at a higher pressure, and the new one which burst showed no corrosion, and the plates had borne a high tensile strain. The explanation was simple, as the old plates had been particularly good and tough, and the new plates so hard and brittle that they could not accommodate themselves to the strain of unequal expansion and set up dangerous seam-rips. This unequal expansion had been wisely stated to be a greater strain to many boilers than that from internal pressure. In fact, some boilers had failed from this cause when heated before they had been exposed to pressure. Most of the well-known and favourite types of boiler were the results of long attention and care to provide sufficient accommodation for the unavoidable unequal expansion in such complicated structures.

Mr. R. D. Munro observed that the Author, in referring to collapse of furnace-tubes, had stated that the results of such collapses were rarely of so serious a nature, and that he could only remember one case during the last twenty years in which shortness of water led to the destruction of the boiler-shell. He remembered three very serious cases of this nature within the last five years, two of the boilers being of the Lancashire type of maximum size, and one of the Cornish type. He also remembered about six instances of vertical boilers which had been displaced and thrown to considerable distances, owing to collapse of the fire-boxes. The Mr. Munro.

Mr. Munro. danger of collapse of the furnace being the occasion of serious explosion was one that should be kept prominently before steam-users, as although many collapses occurred without such serious results, the probability was that, with the rise of pressures now so general, disastrous explosions would occur more frequently from this cause. Under the heading of faulty material and construction, reference had been made to the explosion of two boilers, one of the Lancashire type and one of the vertical type, by the Author, who considered that, "in both of these cases a severe hydraulic proof-test would have revealed the defective construction." A severe hydraulic proof-test was seldom recommended by responsible engineers, and it was questionable if even a proof-test of twice the working-pressure would have revealed the defects in the boilers in question. He had every reason to believe that the vertical boiler referred to (the particulars of which he had investigated at the time of the explosion) had been tested repeatedly in the course of its service, and at none of the tests had there been anything to indicate the existence of such a gross and culpable piece of workmanship as that which had caused the explosion. He was astonished that the Author should suggest or even imply that the condition of such important matters as material and construction should be left over to be determined by a hydraulic test. It was well known that such defects as those to which the Author had referred could only be satisfactorily guarded against by inspecting and testing the material where it is manufactured, and thereafter by careful examination of the work whilst the boiler was in process of construction.

Mr. Shaw. Mr. G. H. Shaw desired to ask the Author whether double butt-straps had been tried for the longitudinal seams of locomotive boiler barrels, and if so, whether they had had any effect on the grooving, as it seemed to him that if it was due to the local straining of the plates caused by bending action, the double butt-straps should be the means of its prevention.

Mr. Sheffield. Mr. G. H. Sheffield, referring to the Author's remarks on the grooving of the angle-bar attaching the end plate to the shell, *Fig. 4*, had observed defects of that nature and attributed them to the excessive rigidity of the angle-bar ring. When a boiler, fitted in this way, expanded longitudinally, there was a tendency to force open the angle-bar at the most rigid point, viz., the root of the angle, which resulted in a laminated fracture. The action varied with the pressure and temperature in the boiler. There was no doubt that the support afforded by gusset-stays riveted to the end and circumferential plates was unequally distributed and

Mr. Sheffield.

aggravated the tendency of the angle-bar to groove. For these reasons he advocated flanged ends with large radii and stays, so that the longitudinal expansion was more gradually and evenly distributed than when angle-bar rings and gusset-stays were used. He considered that a single uptake for large vertical boilers was detrimental to their efficiency, inasmuch as the heat of the furnace was concentrated on one point, resulting in uneven evaporation; and furthermore the flanged ring attaching the uptake to the fire-box crown-plate was a source of weakness, as it did not compensate for the material cut out of the fire-box crown-plate, and was subject alternately to excessive tension and compression. Vertical boilers, intended for high pressures, and of more than 4 feet in diameter, should be fitted with through tubes, and the fire-box crown-plate should be attached to the shell crown with vertical stays. This arrangement, of course, necessitated the use of a smoke-box. He endorsed the remarks of the Author on the inadequate circulation around fire-boxes due to defective design, and had already pointed this out in reference to the fire-boxes of locomotive boilers.[1] In large vertical boilers it was not good policy to sharply flange out the base of the fire-box and rivet it direct to the shell, because it was impossible to clean out the so-called foundation-ring; consequently grooving and corrosion were started through the base of the fire-box being filled with a solid deposit. Although the plea of a little extra expense might be set up, yet a solid foundation-ring for large vertical boilers was more consistent with a finished design than riveted angle-bars or flanged plates, and moreover, the base of the fire-box offered ready facilities for cleaning out the boiler.

Mr. Fowler.

Mr. W. H. Fowler, in reply to Dr. Emery's remarks on the defective character of some of the flanged connections illustrated in *Figs.* *4*, *5*, *12*, *13*, and *14*, which he stated were practically unknown in the United States, wished to point out that the boilers shown in the *Figs.* referred to should not be taken as at all representative of good English practice, but rather as defective exceptions which, partly as a result of their faults, had eventually resulted in failure.

The bracing of cambered ends in small vertical boilers was frequently adopted, but there was sometimes an objection to these stays in practice, in that they interfered seriously with free access for the purpose of inspection, and it was the freedom of access to

[1] Minutes of Proceedings Inst. C.E., vol. cix. p. 383.

Mr. Fowler. the interior which largely determined English boiler-makers in land practice to favour gusset- rather than longitudinal bolt-stays in Lancashire and Cornish boilers. Bolt-stays were also used in conjunction with gussets for high pressures, but the flat ends of these boilers as a rule were so strong that the bolt-stays could be dispensed with. Indeed, they were generally regarded as a "stand-by," and left with a fair amount of sag or slack in them so that they were not called upon to bear any serious stress under normal conditions.

Judging from the high boiler-explosion rate which prevailed in the United States as compared with other countries, it would appear that American practice in boiler construction was either defective, or that boilers subsequently received very improper treatment. As far as the Author could learn, the excessive number of failures in America was due to the use of a low factor of safety coupled with the employment of unsuitable material, cast-iron being frequently adopted for the heads of drums, &c., which in this country would be made of wrought-iron or steel. In addition to this the equipment of boilers was often of a defective character, single instead of duplicate water-gauges being used, while the safety-valves were often of defective design and grouped with other fittings on a common opening. Steam-domes and drums were now seldom adopted in English practice, anti-priming pipes, fixed near the crown of the boiler and coupled direct to the outlet for the stop-valve, being found quite as efficient and generally used in preference.

Referring to Mr. Isherwood's remarks as to the comparative scarcity of boiler explosions, it was true the number of these disasters in this country had, during recent years, been greatly reduced. In the United States, however, the number far from diminishing had steadily increased during the ten years ending 1893, a carefully compiled return for that country giving a total of 2,113 explosions, resulting in the deaths of 2,652 persons, or an average of 211 explosions and 265 persons killed per annum. It was difficult to compare these exactly with similar figures for Great Britain, since every mishap or fatality in connection with the working of a steam-boiler plant in this country was investigated and reported on by the Board of Trade; but it was probably understating rather than overstating the case to say that the explosion-rate and resulting death-rate were at the present time ten times as high in America as in this country, although the number of boilers in operation was probably not far from the same in each case. Mr. Isherwood's suggestion as to the adoption

of a hydraulic test every six months of "two to four times" the working load was in the Author's opinion not only unnecessary but open to grave objections. With a factor of safety of six, which was about the limit adopted by English engineers in boiler practice, it was not wise to apply the hydraulic test to more than double the working-pressure even with new work. If a test of four times the working-pressure were applied it would mean that boilers would require to have a factor of safety of twelve to avoid the risk of injury by the test. Such a factor for the pressures now in use would involve exceptional thicknesses. In cylindrical marine boilers, for example, it would mean plates between 2 inches and 3 inches in thickness, which, in turn, would give rise to many difficulties in the working of the boilers from overheating and unequal expansion, &c. Apart, however, from these considerations, English experience showed that a factor of safety of six was ample with anything like ordinary precautions. Mr. Isherwood's statement that however faulty the material or construction of a boiler might be, it could not explode if it successfully withstood such a hydraulic test as suggested, was, in the Author's opinion, not borne out by facts. The hydraulic test was occasionally a valuable supplementary aid to visual inspection, especially as regarded parts which were difficult of access, or whose strength was indeterminate for other reasons. It should not, however, be regarded as a substitute or relied on exclusively. Instances had occurred when boilers had exploded after withstanding a water-test to a much higher pressure than that at which they were worked. The indiscreet application of the hydraulic test to a serious extent might do more harm than good by distressing the material. The test should always be made under skilled supervision and coupled with careful gaugings in order to ascertain that no permanent injury had been done to the structure. The behaviour of the plates in the experimental boiler explosion at Sandy Hook, as described by Mr. Isherwood, was most extraordinary, and nothing approaching it had ever been met with or recorded in the Author's experience in connection with boiler explosions in this country. That the plates in a boiler should be capable of being stressed to the point of rupture, and that the rivet-holes in the seams should become so enlarged as to permit of the rivet-heads "slipping uninjured through the holes," which then "recovered their normal diameter by the elasticity of the metal as soon as the stress ceased," was most remarkable. He had seen many splendid specimens of material used for boiler construction, but never any that would behave in such a manner. Mr. Fowler.

Mr. Fowler. Instances had been recorded in which flat surfaces stayed with screwed studs had been bulged between the stays and the holes enlarged so that they heeled over the slightly riveted end of the stay without damaging the thread; but this was different altogether to the action described by Mr. Isherwood, which was at variance with all experience respecting the behaviour of iron and steel.

These remarks might be taken in a measure as a reply to some of the comments made by Mr. Munro. He did not, however, in the Paper "suggest or imply that the testing of such important matters as material and construction should be left over to be determined by the hydraulic test," as Mr. Munro had stated. On the contrary, in his opinion the material of all boilers should be tested before it was used, while the construction should be carefully examined in progress as well as tested by hydraulic pressure when complete. But in the case of boilers which were already in existence, and the history of which was uncertain, the application of a careful hydraulic test was occasionally a great help to inspection, and sometimes the only means of obtaining information as to the quality of the material and workmanship. It was as illustrations of the value of the test for this latter object that the references to the cases in the Paper were made. With reference to Mr. Munro's remarks regarding the effect of shortness of water, the Author had alluded strictly to boilers of the Lancashire and Cornish type, and he adhered to the statement he had made. He was aware that certain collapses of furnace-tubes had been accompanied with ruptures of the shell, but these had not been simple cases of overheating from shortness of water. There had been many cases of "vertical boilers which had been displaced and thrown a considerable distance owing to the collapse of the fire-boxes." He did not, however, question this or assert anything to the contrary.

The question asked by Mr. Shaw respecting double butt-straps and grooving had been raised and answered in the Paper in reference to grooving in locomotive boilers. The cause of the grooving alluded to in *Fig. 4* had not been the "excessive rigidity of the angle-bar ring," but the unequal incidence of the stress. In this particular case the trouble arose because the angle-ring and the end-plate were too light. He quite agreed, however, that a flanged end well curved at the root was, when it could be adopted, better than an angle-ring attachment. Bolt-stays were better than gussets possibly in some cases, but on the other hand, gussets possessed decided advantages in many instances, and often afforded

opportunities of access for inspection and cleaning which would be impossible with bolt-stays. The use of bolt-stays in vertical uptake boilers was sometimes necessary, but at the same time it was possible to bind the crown of the fire-box and shell in this class of boiler too rigidly together, and he had met with instances in which the excessive rigidity arising from this cause had given rise to grooving of the uptake. He quite agreed, however, as to the superiority of solid block rings at the base of the water-space in small vertical boilers as compared with the plan of flanging out the base of the fire-box, as shown in the sketches of some of the boilers which had failed. The method of flanging not only reduced the thickness of the material, but in the case of iron plates rendered them more liable to corrosion. Mr. Fowler.

---

5 February, 1895.

Sir DOUGLAS FOX, Vice-President, in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Member.

Alfred Barton Brady.
Robert Cope Hardy Davison.
George Higgins.
William Cuthbert Lewis.
Alfred Lee Pogson.
David James Ross.
George Gilbert White.

And that the following Candidates had been admitted as

Students.

Henry Augustine Bailey.
James Golder Robinson Baxter.
Schaffhausen Angell Colam.
Edward Albert Duffield.
Herrmann Oscar Eurich.
Michael Birt Field.
John Garnar Flood.
Alfred Stead Garrett.
Frederic William Gaskin.
Donald Charles Graham.
Leslie Leopold Rudolph Hausburg, B.A.
James Welby Madeley, B.A.
Frederick Arthur Molony.
Matthew Alexander Murphy.
Blamey Stevens.
John Louw de Villiers.

The Candidates balloted for and duly elected were: as

Members.

William Langton Coke.
John Edward Goldwyer.
Maurice Edwin Kernot.
William enry Routledge.
Matthew Henry Phineas Riall Sankey, *Capt. R.E.* (Retired).

Associate Members.

Edward Hazledine Barber, Stud. Inst. C.E.
Lewis Adolphus Bernays, Jun.
David Butler Butler.
Daniel Frederick Cooksey.
Edward Alexander Cullen.
Robert Washington Dana, B.A.
John Smith Dawson, Stud. Inst. C.E.
James Robertson Douglass.
William Liston Douglass.

Associate Members—continued.

Francis Bragg Drake.
John Alfred Edmondson.
Frank Garrett, Jun., Stud. Inst. C.E.
Thomas Stephen Gilbert, B.E., Stud. Inst. C.E.
Francis Edward Hamond, Stud. Inst. C.E.
William Harker.
Stanley Arthur Lane.
Harold Macandrew, A.R.S.M.
Thomas Ivor Moore.
William George Perrott, B.E.
Frederik Benedikt Petersen.
Robert Edward Phillips.
Patrick Joseph Prendergast.
Edward Yelf Radley, B.A.
Joseph Peter Robinson, Stud. Inst. C.E.
James McKean Rowbotham.
Robert John Scott-Bushe.
Samuel Nathaniel Squire.
Alfred Still, Stud. Inst. C.E.
William Tower.
Henry Arthur Douglas Wathen.
Stephen Watkins.
William Smart Welton, Stud. Inst. C.E.
Arthur John Williams, Stud. Inst. C.E

(*Paper No. 2859.*)

"The Mechanical and Electrical Regulation of Steam-Engines."

By John Richardson, M. Inst. C.E.

Although the subject of governing steam-engines has occupied the attention of engineers for more than a century, it is still imperfectly understood by users of steam. In spite of the fact that many excellent means of automatically governing the speed of an engine are known, it is not uncommon for a large and important engine to be without any reliable governor, and to depend entirely upon regulation by hand—the governor with which it is fitted being regarded merely as an indicator of the varying speed, to warn the driver to open or close the stop-valve.

The great speed and delicacy of many of the machines used in the textile and similar industries, and the requirements of engines for the generation of electricity, have called forth many new methods of governing, particulars of a number of which will be described in this Paper, some as types to be avoided, and others to be imitated. The Author does not intend to deal with the theory of the action of steam-engine governors, as Papers upon the subject by Professor Dwelshauvers-Dery[1] and others have already been printed by the Institution; but he proposes to deal with the practical results which can be obtained from a great variety of types that have come under his personal observation, and the causes of

[1] Minutes of Proceedings Inst. C.E., vol. civ. p. 196, and vol. cx. p. 276.

their failure or success.[1] A good governor should be reliable, simple in construction, easy to drive, and instantaneous in its action, both in increasing as well as in reducing the supply of steam. It should not reduce the power of the engine to which it is applied, but should tend to economise steam; and, while allowing for great variations in the power of the engine, it should maintain a practically uniform speed.

Mechanical Regulation.—The form of governor in almost universal use until a few years ago was that invented by Watt, Fig. 1, Plate 3. It was connected generally through several levers and rods with the wing throttle-valve shown in Fig. 2. This governor is still largely used, and is reliable and simple. It can prevent an engine from racing when the load is removed, and may regulate it within certain limits, but it cannot secure uniformity of speed under greatly varying loads. The speed of revolution at which the balls can be maintained when in the position *2* in the Fig., is widely different from that required when they are in the position *1*, and no possible increase of speed could raise them beyond the position *3*.

The Porter governor, Fig. 3, is a marked improvement upon the Watt governor. A heavy central weight A, offers a constant resistance to the lift of the balls, which are caused to revolve at a much higher speed than would be required without the central weight. This governor gives a much wider range of travel with a smaller difference of speed than the Watt governor, and is largely used both in connection with throttle-valves and with some forms of expansion-gear.

A form of governor possessing some further advantages, which was designed by the Author about twenty years ago, is shown in Fig. 4. In this governor, the arms, instead of being suspended from a single fixed point, are suspended from two points and cross each other. The effective length of the arm, being that between the centre of the ball and the point A, where the arms intersect, increases as the balls rise, the increase of length being shown by the difference between B and C. The balls are kept close together at their lowest position, and thus as they diverge the effective length of arm increases more rapidly than the rise of the balls. As is well known, it is quite easy to proportion governors of this class so that the sleeve will have a

---

[1] See also P. W. Willans on "The Electrical Regulation of the Speed of Steam-Engines," Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 166; and H. B. Ransom on "Fly-Wheels and Governors," *ibid*, vol. cix. p. 330.

large range of motion with very small difference in speed. While this is a great advantage, it is obtained only at a sacrifice of power, and when rendered isochronous such a governor is practically useless for controlling any valve or gear which requires much power to move it, as, at a fixed speed, the weighted ball will stand indifferently at any point between its lowest and highest positions. To be of the greatest use a governor must have great lifting-power, forcing-power and stability at every point of its range, and a large motion of the sleeve in proportion to the difference in speed of revolution. The ordinary pendulum governor is stable, but unless it is of great size in relation to the engine, it has but little lifting- and forcing-power; and in the Paper communicated to the Institution by Professor Dwelshauvers-Dery,[1] he states that as a result of experiments, "The logical conclusion is, that the best governor cannot, when the greatest fluctuations in the load of the engine occur, prevent the velocity from varying by at least 10 per cent." These conclusions applied to an ordinary pendulum governor, and are no doubt correct, but much better results may be obtained by the combination of such a governor with a spring.

In such a combination an entirely new set of conditions is presented. Gravity, which is the only force causing the balls to close or fall in the Watt governor, may now be practically disregarded, for a much stronger force is substituted for it. Such a governor can, therefore, act equally well in any position. One of the earliest examples of this kind of governor is that designed by the Author in 1869, shown in Fig. 5. In addition to the spring, another feature is introduced, viz., the lengths of the arms are so proportioned that the balls diverge in nearly a straight line for a considerable distance. The centrifugal force generated by revolution at a given speed at a radius of 4 inches, is manifestly much less than that generated at the same speed with a radius of 8 inches, and this large difference is counteracted by the increasing force of the spring as it is compressed. Such a governor can be made to give a travel of the sleeve of, say, 3 inches, for a change of velocity of only 4 per cent., and it has a lifting- and forcing-power of 100 lbs.; that is to say, when revolving at a speed corresponding to its lowest position, it would require an upward pressure of 100 lbs. on the sleeve to raise it to its highest position. The force required to move it through the same distance when not revolving is 200 lbs. A variety of this type of

[1] Minutes of Proceedings Inst. C.E., vol. cx. p. 277.

governor, introduced by Proell about the year 1884, is illustrated in Fig. 6. In it a heavy central weight is substituted for the spring, though the action of the arms is similar. Instead of the increased force of a spring, a weight is lifted at an accelerated speed as the balls diverge. This governor is extremely sensitive, but has practically no lifting- or forcing-power, and needs a dashpot to give it stability. Something in the nature of a dashpot is introduced in the governor and is shown in the section, Fig. 7, but as this contains air only it is almost ineffective. A perfect governor should not need a dashpot, but if one be used it should contain some incompressible substance which can escape only through a small aperture from one side of a piston to the other, as shown in Fig. 8. In the opinion of the Author, however, all such attempts to give stability to a governor are but expedients to minimise an evil, which might and can be entirely eliminated.

Until comparatively recently governors for controlling the speed were almost universally applied to engines by means of the wing throttle-valve shown in Fig. 2. This valve, though simple in construction and easy to move, is difficult to fit so as to remain steam-tight. One of the first requisites of a regulating valve is that it should be able to entirely stop the admission of steam, and this becomes more important as the steam-pressure becomes higher. The valve shown in Fig. 9 is a considerable improvement upon the butterfly-valve. It is easier to make and easier to work, and for regulating variations in load with a good governor it acts well. It is, however, more difficult to obtain a perfect fit with it than with a piston-valve, so that the valve will move without friction, but still be sufficiently tight to shut off all steam. Careful experiments made with free-running engines show at least 15 per cent. of variation between all load on and all off, the small space required to pass sufficient steam to drive an unloaded engine being almost incredible. The equilibrium double-beat valve, Fig. 10, has been found by the Author to give the best results of any kind of throttle-valve. The arrangement shown in the Fig. is that of a valve not quite in equilibrium when closed—the area of the upper part being so much greater than that of the lower, which is equal to the area of the stalk, that the valve has a constant small upward pressure whether on or off its seat, which makes it move readily to respond quickly to minute changes of the governor, there being no slack or back-lash. Combined with a well-proportioned high-speed spring governor, it will, with changes of load not exceeding 75 per cent. from the maximum, maintain a speed within 5 per

cent. of the normal; but the difference between maximum load and no load is nearly 10 per cent. with a steam-pressure of 100 lbs. per square inch, the difference being much less with a lower pressure of steam. Another form of valve which is largely used in England and in America is shown in Fig. 11. It works nearly in equilibrium, the stalks being small, and the two disks being of the same diameter. Combined with its own governor, it will maintain a nearly constant speed with moderate changes of load, but it fails to cut off the whole of the steam, and thus with light loads, or no load, the variation of speed is very considerable. Careful experiments upon it show a variation of speed of 14 per cent., and it was found impossible to reduce the difference below this amount, when the comparison was made between the greatest load the engine could carry at a definite speed, and no load. Though there are many varieties of throttle-valves for regulators, they are all more or less varieties of the four types described, viz., the butterfly, the piston, the disk, and the equilibrium double-beat valve; and Table I below shows

TABLE I.

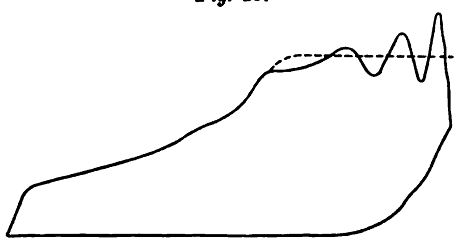
Pressure at Stop-Valve.	Revolutions per Minute. Light Engine.		Revolutions per Minute. Loaded Engine.		Permanent Variations in Speed due to Change in Load.		Temporary Fluctuation in Speed due to Change in Load.				Brake HP.		Time Coming to Rest.	
	English Shaft-Governor.	American Centrifugal-Governor.	English Shaft-Governor.	American Centrifugal-Governor.	English Shaft-Governor.	American Centrifugal-Governor.	English Shaft-Governor.		American Centrifugal-Governor.		English Shaft-Governor.	American Centrifugal-Governor.	English Shaft-Governor.	American Centrifugal-Governor.
Lbs. per sq. in.					Per cent.	Per cent.	Revs. per Minute.	Dif. per cent.	Revs. per Minute.	Dif. per cent.			″	″
50	364	345	352	305	3·2	11·5	350–390	11·1	..	..	6·00	5·2	0 20	5
60	365	350	352	310	3·6	11·5	350–400	13·9	310–360	13·9	7·80	6·9	0 40	10
70	362	355	350	320	3·2	9·8	350–380	8·7	310–370	16·7	8·75	8·0	1 15	25
80	360	360	350	325	2·8	9·7	350–390	11·1	310–370	16·7	9·75	9·0	0 20	30
90	362	362	352	305	2·8	15·2	350–380	8·7	280–370	25·0	12·40	10·8	0 50	10
100	364	362	350	305	3·8	15·2	350–380	8·7	280–370	25·0	13·00	11·3	0 50	15

English shaft-governor as in Fig. 15.
American centrifugal-governor as in Fig. 11.

about the best results that can be expected of them. All throttle-valves, though simple and easy to manage, have necessarily the objection that they regulate the speed by altering the pressure of steam in the steam-chest and cylinder; and thus cannot fulfil two of the essential conditions of a good governor, namely, that it should not diminish the power of an engine, and that it should increase rather than diminish the economy of steam. For many purposes, however, where great delicacy of governing is not needed, such a valve as that shown in Fig. 10 is all that is required.

The next important type of governor is one which controls a slide-valve, and which regulates the speed either by regulating the travel and angle of the main valve, or by limiting the admission of steam through controlling the angular advance and travel of a cut-off slide working on the back of the main valve. Governors of the former type generally revolve with the crank-shaft, and are known as shaft-governors—one of the first of these to be used being

Fig. 13.



that made by the Author in 1869, shown in Fig. 12. In this case a governor of the spring type, Fig. 5, is used in connection with an adjustable eccentric. The object to be attained is to move the centre of the eccentric in a straight line at right-angles to the crank, thus maintaining a constant lead while varying the travel, and the point of cut-off. This is accomplished by a pair of wedges A A moving in the same direction and connected to the moving slide B. *Fig. 13* is a copy of the first diagram taken from an agricultural 8-HP. portable engine, fitted with this type of governing gear. It will be observed that, unlike some other adjustable eccentrics in which the eccentric floats on the arm of the governor, in this case the eccentric is driven by the square part of the shaft; and, while the wedges adjust its position with regard to cut-off, yet at the same time they hold it firmly at all points. This is an important advantage, and permits its application to an ordinary simple flat slide-valve; while governors which depend upon the stability of

position in the balls or weights, need an equilibrium slide-valve because they are not sufficiently stable to work with a flat slide. A considerable number of these governors have been made, but twenty-five years ago the expansive working of steam was not so well understood and appreciated by users of steam as at present; and further, the governor in that form, owing to the large space occupied, was not applicable to many types of engine.

A modification of this gear, occupying much less space but working on exactly the same principle, is shown in Fig. 14, Plate 3. The eccentric is guided and driven from the slots in the plate A, and is caused to travel at right-angles to the crank by means of the wedges B B, which are again moved by the arms of the governor, the centrifugal force of the balls being counterbalanced by the spiral springs C C. The wedges B B are each double, that is to say, a wedge above and one below, this being necessary as the shaft has to be both pulled and pushed. When connected at their ends, the two wedges become a plate with an inclined slot in it. A much simplified modification of this arrangement has been made by Mr. Buck, a member of the Author's staff, and is illustrated in Fig. 15. In this, the two flat plates working in planed grooves are replaced by a disk E, partially revolving on the boss of the casing. An inclined slot is cut in this disk, and the incline is bent to a radius equal to its distance from the centre. In this slot a projection from the eccentric slides, and is moved at right-angles to the crank as before. This partial revolution of the disk is given by the weighted arms of the governor, as in the case of the straight wedges, but in this case through the links D D. The whole of the governor is contained within the rim of the fly-wheel or driving-pulley of the engine. As will be seen from examination of the governor, which is laid on the table, the whole of the driving is done by the disk, the eccentric is held rigidly in position by the slots and wedges which are at right-angles to each other, and there are nevertheless four points in each revolution when it is quite free to be moved and adjusted by the governor-arms. With a properly-proportioned governor of this type, there is no difficulty in maintaining a practically constant speed of the engine with ordinary changes of load, and with so wide a range as between three-quarters and zero in the admission of the steam; in other words, between maximum load and no load, the variation of speed can be reduced to 3 per cent., which is sufficiently near for all practical purposes. With this method of governing there is, of course, no wire-drawing of the steam, and thus no reduction in the power of the engine; and further, the full boiler-pressure being always attainable, the steam

can be cut off early, and the maximum economy obtained from it. Table I shows the difference in power between the same engine with this governor, Fig. 15, and with an American governor, Fig. 11, the engine being loaded in the latter case till the speed fell 10 per cent. below the speed when unloaded, and with the wedge-governor to 3 per cent. below that speed.

TABLE II.

—	Fig. 11.	Fig. 10.	Fig. 15.	Fig. 19.
	Revolutions per minute.	Revolutions per minute.	Revolutions per minute.	Revolutions per minute.
No load	338	320	312	96
Full "	300	300	300	95
Variation per cent. .	12·66	6·66	4	1
	29½ B. HP.		35 B. HP.	

As shown by Table I, which is a further comparative test, the American pattern of throttle-valve governor reduces the power at all pressures much more than shaft-governor, the latter allowing the engine to develop on an average about one-sixth more power with the same pressure of steam. With the shaft-governor, the variation in speed is between 2¾ per cent. and 3½ per cent., and with the throttle-valve 10 per cent. and 15 per cent. With the more delicate governor, the fluctuation, though less in quantity, is naturally greater when measured by time, in one case amounting to seventy-five seconds. In this case, however, the extreme variation for the first second was only 8·7 per cent. and gradually fell to zero. With the less sensitive governor rest was arrived at in twenty-five seconds, but the variation was more than twice as great, viz., 16·8 per cent. Another important difference is remarkable, viz., that with the shaft-governor the variation is nearly all upward; thus, if the normal speed is 352 revolutions per minute, when the load is suddenly applied the decrease of speed is only two revolutions per minute, and the variation causes an instantaneous upward rise gradually coming to rest with decreasing oscillations. On the other hand, with the throttle-valve the sudden change is downwards, gradually rising with few oscillations from 310 to 350. It should be noted that the changes in load were made suddenly, all being put on and taken off at one time. With gradual changes there is practically no fluctuation either with the shaft or throttle-valve

governor. Table III shows the slight variation in speed of an engine fitted with this governor driving an electric-light installa-

TABLE III.—SHOWING UNIFORMITY OF SPEED OF AN ENGINE FITTED WITH A SHAFT-GOVERNOR.

Revolutions per Minute.	Amperes.	Revolutions per Minute.	Amperes.
214	0	208	380
213	50	209	280
213	65	211	180
210	80	213	80
209	180	214	0
209	280		

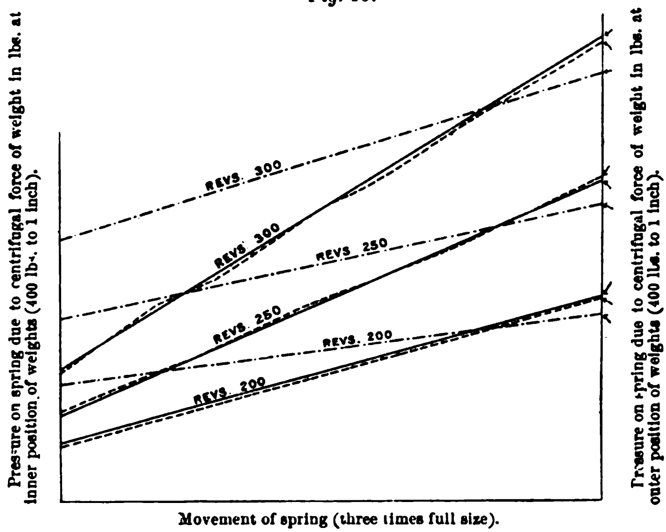
tion, from which it will be seen that the total variation in speed is slightly under 3 per cent. from no load to full load, and that with variations of over 50 per cent., or from 280 to 380 amperes, the variation in speed is only 1 revolution per minute, or less than ½ per cent. The power of this governor, to prevent any of its parts from being moved out of their proper positions, is very considerable, the springs requiring a force of 1,100 lbs. to move them from the extreme inward to the extreme outward position.

It may be pointed out here that the positions of the weights and the strength of the springs does not work out strictly according to the recognised laws of centrifugal force. These laws are of course correct for freely moving bodies, but are not true for bodies moving freely at one part and suspended at another from a point fixed with relation to the centre round which they revolve. The diagram, *Fig. 16*, shows graphically the relation between the calculated, experimental and theoretical pressures of a spring resisting a certain centrifugal force generated by a weight revolving at a constant speed but at different radii. The slightly curved short-dotted lines show the variation in pressure which experiment indicates is actually required when the weights are suspended on pins, and the straight line shows the calculated strength of the spring when allowance is made for this. The Author is indebted to his assistant, Mr. Wansbrough, for assistance in working out this method of calculation, and the diagram shows that in a large number of cases it is correct. It will be noted that the lines intersect before the point of highest pressure, and the extra strength of spring beyond this

point exactly corresponds with the 3 per cent. increase of speed allowed with no load.

Link expansion-gear is chiefly identified with the name of Allan, and was first introduced in Europe at the French Exhibition of 1864. Allan worked, as is well known, with one eccentric; but the most common form of link expansion-gear is that shown in Fig. 17, Plate 3, one eccentric being used to drive the main valve B, which thus has a constant lead, compression and exhaust; another eccentric set at an angle to it controlling a separate cut-off A, fitted on the back of the main valve. The stroke of this cut-off

Fig. 16.

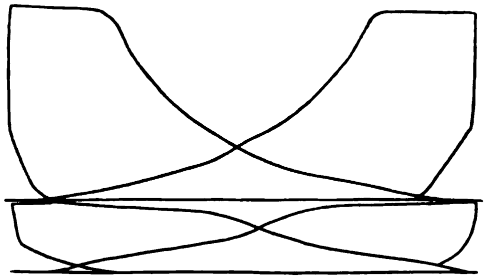


Pressure of spring, calculated . . thus ————
" " " by experiment . " - · - - - - -
" " " theoretical . . " — · — · —

valve, together with the point of cut-off, is regulated by the position of the valve-rod C, with the other end of which the cut-off valve is connected. With this type of gear a range from nearly three-quarters to zero can be obtained, together with a very good distribution of steam as shown by the diagrams, *Figs. 18* and *18a*, taken from an engine fitted with this gear. Its success depends very much upon the type of governor used in conjunction with it, which must have a wide margin of stability. The Author has experimented with Watt, Porter and Buss governors, with unsatisfactory results, as all needed a dashpot to give them stability and to prevent the angle of the link causing oscillation in the governor.

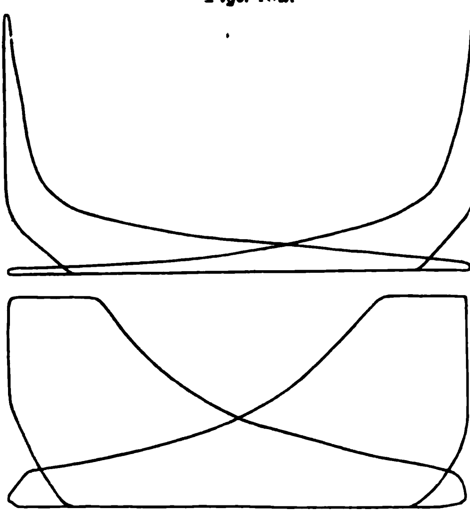
The dashpot arrangement cured this, but of course rendered the governor more sluggish in its action, so that with wide changes of the load there were great temporary changes of speed; though the engine would settle down to approximately its normal speed

Figs. 18.



within one or two minutes. With the governor shown in Fig. 17 there is no need of a dashpot, the change of position occurring instantaneously and the acceleration of speed being a matter of

Figs. 18a.



one or two seconds only. The stability of the governor is very great, and although the arms, balls, and spindle together weigh only 53 lbs., yet it would require a force of over 400 lbs. to move it to its highest position when at rest. When it is running at a

speed corresponding to its lowest position a force of 216 lbs. would be required. With an acceleration of only 4 per cent. it overcomes a further pressure of 200 lbs. It will be noticed that the balls move outward in a practically straight line in the same way as the balls of the governor shown in Fig. 5. For engines of moderate size of, say, 50 or 60 HP., and working with steam-pressure of 80 lbs. per square inch or less, such a form of expansion-gear is one of the best that can be used.

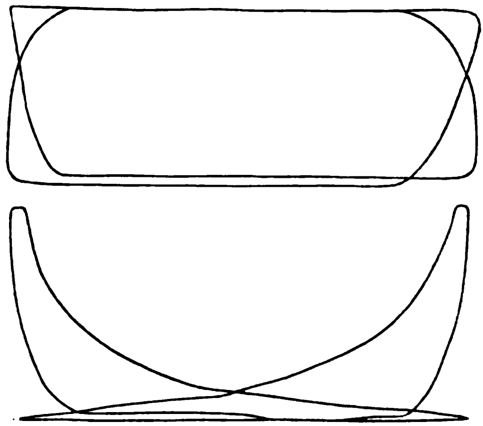
The much higher pressures, however, which are necessary for the most economical use of steam, necessitate the use of valves which will work in equilibrium or nearly so. These are mainly of three kinds—piston-valves, rotating or circular valves like the Corliss, or double-beat valves like that in Figs. 19 and 20, Plate 3. Slide-valves absorb a great part of the power of an engine working with high-pressure steam. The Author has made a series of experiments showing the amount of this friction, but would now only state that his experiments show it to absorb often more than 10 per cent. of the whole power exerted by an engine; while the power required to work the equilibrium valves shown in Fig. 19 is quite insignificant, and is almost independent of the pressure of steam used. This type of valve is much used in connection with a variety of valve-gears. That shown in Figs. 19 and 20 is believed by the Author to combine many advantages not secured by the others. It consists, as will be seen from Fig. 20, of a double-beat valve A, guided by a central stem. The valve is lifted by the steel stem B, at the upper end of which is a grooved piston D, working practically air-tight on the cylinder D^1, a light spring pressing it down. A small hole at the bottom of the cylinder is in communication with the upper part of a valve-box C, in which works a small ball-valve. The valve is shown in section at D, and to a larger scale at C^1. The object of this piston and cylinder is to control the valve as it descends upon its seat, and thus to prevent a disagreeable noise and unnecessary wear. As the spindle with its piston and valve rises, air is drawn in through the valve E, when it is suddenly relieved and falls, the contained air moves slowly through a fine hole in top of the valve-casing, and the valve A is relieved of inconvenient shock. The arrangement described, or some modification of it, is used by several English and Continental makers of steam-engines. The peculiarity of this gear lies in the method by which the point of cut-off is controlled by the governor. The valve-spindle B is lifted by the lever H when the outer end of the lever is depressed. This depression is caused by the eccentric K, which revolves in equal times with the

engine-shaft. The upper end of the eccentric-rod is attached to a pair of rocking levers J, and also carries a tripper with a steel toe L. As the rod rises, this toe is thrown back, but as soon as it gets above the levers it is allowed to fall to its original position. On the downward stroke of the eccentric the toe of the tripper depresses the lever, raising the valve, until, being pushed out by radius-rods, it releases the lever, and the valve instantaneously falls upon its seat. It will be seen that the more the toe of the tripper overlaps the end of the lever H, the longer it will remain in contact with it on the downward stroke, and thus the valve will remain so much longer open while the lead remains constant. The amount of the overlap is regulated by the governor in a very simple manner. The fulcrum of the lever H is movable, and can be moved from right to left in a straight line in the slot M. The spindle O has two levers upon it, connected by short links P P to a rod Q passing through both fulcrums. The entire movement required is a horizontal motion of this fulcrum, and even in large engines of, say, 500 HP., it is only about $\frac{3}{4}$ inch, and can be moved with the smallest effort. There is, therefore, absolutely no stress upon the governor, and not the slightest tendency for it to work or jump due to the working of the valve-gear. So far from this being the case, when the valve is lifted, the fulcrum is pushed down and so held rigidly in position, the movement of the fulcrum having to take place during the interval when the valve is not being lifted. The range of expansion which can be obtained by this means is very large, extending from zero to seven-eighths, and is shown in the diagrams *Figs. 21* and *21a*, taken from an engine fitted with this gear. The absence of any sensible stress upon the governor enables a very small one to be used; and in practice it is found that a governor even for an engine of 1,000 HP. need not weigh more than 90 lbs. It will be noticed that there is no upper collar to the governor, nor is one needed for its proper working, the weight of the lever N and the small ball hanging from it being quite sufficient to keep it always in contact with the lower collar. An important advantage possessed by this valve-gear results from the fact that it allows of the engine being stopped immediately by merely raising the governor lever; and if a cord from the end of the lever is carried into every room in a factory or a mill, in the event of accident the engine can then be stopped by merely pulling the cord even from a great distance.

Electrical Regulation.—The conditions which obtain for regulating engines driving dynamos are not quite the same as those for

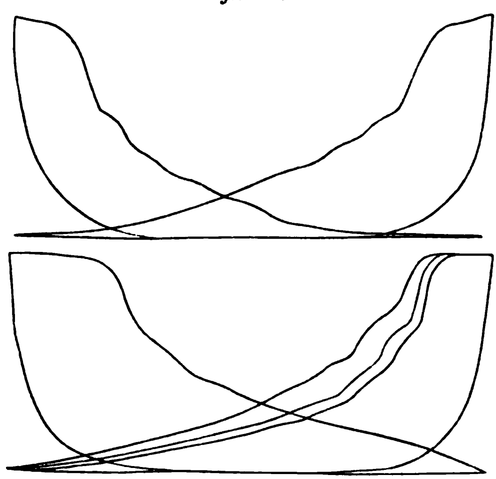
maintaining a constant speed in other machinery. If the electric current produced by the engine be utilized to control its speed, it

Figs. 21.



then becomes possible either to run the engine at a practically uniform speed in connection with a perfectly compounded dynamo

Figs. 21a.



or to run it at a varying speed, maintaining either a constant difference of potentials with a varying current, or a constant current with a varying difference of potentials. Further, by

utilizing the changes in the current to control the engine, it is not only possible, but quite easy, when the load is suddenly decreased, to effect what is impossible with a speed governor, viz., to shut off for a time the whole of the steam-supply before the engine has had an opportunity of increasing its speed, and thus to deprive the engine of steam until its speed has fallen to just what is necessary for the diminished load, the steam-supply being gradually increased until exactly sufficient for the load is supplied. Conversely, when the load is suddenly increased, and before the engine has had time to diminish its speed, the fullest supply of steam is given, and only then diminished to an amount corresponding with such increased load.

In Figs. 22–28, Plate 3, are shown a number of appliances which have been devised and tested by the Author for the electrical regulation of steam-engines. Some of them, however, are shown as examples of what may be avoided, because, though apparently plausible in theory, they fail in practice. Fig. 22 shows the direct drive of a governor by electricity which, though the first successful attempt to control the speed of an engine by the electric current, was an indirect method of attaining the result. The two small maguets under the valve were intended to act as weights to close it, should the current be broken in any way and thus stop the engine, these being of course held out of position during the time the current was passing. In another form of governor, Fig. 23, there is no solenoid in direct connection with the valve, and only a small one E, moving a light lever, at the end of which are two platinum points. This lever and the fixed points A and B are so arranged that when the lever is in contact with the upper point, the small motor C is caused to revolve, and by means of the crank lever F the valve is closed, and of course the reverse action takes place when the lever is in contact with the lower point. By this means it was thought that, as the solenoid at a certain intensity of current must be maintained in one position, when this intensity was arrived at the lever would remain at rest. Careful tests, however, show that this is not so; however small the time occupied in making contact and setting the motion to work, it is enough to cause the engine to vary its speed too much, and the result is persistent hunting. This apparatus, therefore, must be considered a failure, though several modifications of it have since been introduced.

Fig. 24 illustrates a very simple arrangement, in which the equilibrium-valve A, having a spindle projecting through a stuffing-

box, is pressed upwards by the steam with a force due to its unit pressure multiplied by the area of the valve-spindle, say 15 lbs., and is held down by the short arm of the lever B, which has a ratio of 10 to 1, so that the force required is 1 or 2 lbs. The electric current circulating in the two solenoids C holds up two iron cores weighing 10½ lbs., and a very slight variation in the current tends to cause a considerable alteration in the position of the cores, especially when they are placed at the position of maximum effect as in Fig. 24. It is remarkable how slight a movement of the valve is required to effect the regulation. Very careful experiments have shown that for an engine working up to 25 HP. with equilibrium-valves of 2 inches diameter, it required to be raised only 0·003 inch from its seat to run the engine at full speed unloaded; and it needed to be raised only 0·031 inch to run the engine at its full power—the variation or actual lift of valve being thus only 0·028 inch; and, as the ratio of the lever is 10 to 1, the amount of movement of the solenoid cores is only 0·28 inch. When a load is put upon the engine, however, the fall is always much more than this, and occurs instantaneously, and before the engine has had time to diminish its speed. The valve is thus opened for a few seconds three or four times as wide as in its normal position until the engine has received its full extra power; the solenoid then rises to nearly its former position. The reverse action takes place when the load is thrown off; the governor, simultaneously with the reduction of load, closes the valve entirely and keeps it closed until the momentum is so far expended that the engine slightly slows, when the valve is gradually opened, just enough for the reduced load. The action is instantaneous and direct, and there is no hunting. This apparatus is suitable for comparatively small engines, say up to 50 HP., but when large powers have to be regulated by a throttle-valve, it is not economical enough in steam, and the valve would need too large a solenoid to control it within narrow limits, and would absorb too much current.

Figs. 25 and 26 show other forms of governor, with automatic arrangements for stopping the engine in case of failure of the electric current. In Fig. 25, which was the first form used, a heavy weight A is held up by an electric magnet B so long as the current is passing, but is released on the current stopping, when the lever C falling upon the valve-spindle instantly closes it. The spring D and the weight E were for regulating the solenoid to the exact quantity or intensity of current required, as was also the lever F, which, passing over the contacts GGG, disconnects one or

two of the coils out of circuit. A simple way of stopping the engine is shown in Fig. 26, where the weight of the solenoid cores is used to close the valves on breakage of the current, acting through the lever A. While the solenoid is active, the regulation is effected through the lever B, A moving idly, but the instant the current is broken, the cores fall, the lever A presses upon the valve-stalk through the plunger C, and this is free to close; because the small end of the lever B works in a slot in the spindle with clearance upwards, all of its work being done and its only contact being on its lower edge.

The type of valve-gear illustrated in Fig. 27 lends itself admirably to electrical control, and an arrangement to control it by electricity was devised by the Author and Mr. R. H. C. Nevile in 1886. As the power required to move the governing lever A is practically nothing, a small solenoid and slight current is sufficient to effect the entire control of engines of 800 to 1,000 HP. While any current is passing through the solenoid, the engine is under perfect control; but should the current be broken from any cause, the cores B instantly drop, when their weight depresses the lever C and raises the lever A as shown in Fig. 27.

Instead of this arrangement, a speed governor can be used in connection with the electrical governor, so arranged that it does not come into action until the speed has been increased by a certain percentage. This plan also is shown in Fig. 27. This method of governing electric-light engines has been adopted in some important installations, and is very useful when an engine has to be used for sawing or pumping in the day and for electric-lighting at night. Up to the present time, however, no case has come to the Author's knowledge where the safety apparatus has been needed; but it is none the less essential that it should be provided.

Table IV shows some tests of the solenoid and throttle-valve governor made by Prof. Silvanus P. Thompson some years ago; and, so far as the Author is aware, every electrical governor made has continued in use up to the present time—the repairs and wear and tear being inappreciable, nothing being required beyond an occasional grinding of the valves.

Tests recently made of a pair of large engines with the solenoid working the trip-gear show that, after eight years' use, they are practically as good as new. One of the bobbins had in this case short-circuited on the brass flange, causing the wire to heat. A more recent method of construction by winding the solenoid upon a vulcanite instead of upon a brass and copper insulated hollow

collar has prevented this. In connection with this governor a small resistance-box is usually supplied. This is put into circuit with the solenoid, and by its means the amount of current passing through it can be regulated to a nicety, and the speed of the engine adjusted to exactly what is required. Once adjusted, with the same intensity of current, the speed will be modified to maintain the intensity.

In an electric installation covering a large area there is a definite loss of pressure in the mains on account of their length. If, however, a wire be brought from the centre of the illuminated area and attached to the small solenoid A, Fig. 28, a constant

TABLE IV.—TESTS OF THE SOLENOID AND THROTTLE-VALVE GOVERNOR.

Lamps.	Revolutions.	Amperes.	Lamps.	Revolutions.	Amperes.
17	146	10·2	11	96	10·2
17	144	10·2	11	92	10·3
17	143	10·1	11	90	10·3
17	137	10·2	11	89	10·3
17	133	10·2	11	85	10·5
17	119	10·2	5	70	10·0
16	133	9·9	5	60	10·5
16	132	10·1	0	30	10·4 10·6
16	129	10·2	0	24	11·0 11·2
11	107	10·1			Unsteady[1]
11	101	10·0			

intensity of current will maintain a constant position of the solenoid core and will keep the lever B midway between two contact-points. As soon as the slightest difference of pressure arises, not only does the main solenoid core rise and cut off the steam, but contact is made between B and C, exciting the small electro-magnet E; through the armature F pulling the spindle G with its revolving disk H into contact with the disk I; and through the gearing K causing the contact lever L to move so as to cut off one or two of the resistance-coils. By this means the main solenoid is intensified and the speed is reduced until the lever B regains its mean position. It will be seen that the electric-work, while very delicate, is in-

[1] The unsteadiness noted when no lamps were in circuit is due to the passing of the sections of the armature past the field-magnets at the slow speed, each section causing a pulsation of the needle of the ammeter.

significant in quantity, the real work being done by the driving-cord M from the dynamo shaft. The two cells O and N are required to cut out the current should there be a tendency for the lever L to travel too far. In practice, however, these have never been needed. In fact, the action of the simple solenoid working direct on to the expansion-gear gives such satisfactory results that there is no need of the relay and supplementary control shown in Fig. 28, and it is illustrated only to show within what very fine limits electric control can be carried if desired.

In bringing under the notice of the Institution the various methods of regulating steam-engines to which allusion has been made, the Author, whilst fully aware that he has traversed but a small part of a very wide field, hopes that some novel and valuable facts may have been brought forward.

The Paper is accompanied by twenty-eight drawings, from which Plate 3 and the *Figs.* in the text have been prepared.

Discussion.

Sir Douglas Fox. Sir DOUGLAS FOX, Vice-President, said the subject of the Paper was one of considerable and growing importance, especially when steam-engines were being used for such constantly varying loads, and he was sure it would be desired to thank the Author not only for the Paper, but for the diagrams and models submitted with it.

Mr. Richardson. Mr. JOHN RICHARDSON, after explaining the working of the apparatus exhibited, said that when the engine was used for many purposes, as in the case of comparatively large private installations at country houses, for driving dynamos, in addition to performing other work during the daytime, the mechanical governor was set at a slightly higher speed than the electrical governor; and thus it never came into action so long as the electrical governor had control, but could work quite independently when the latter was out of play. In case of accidental breakage of the electrical governing wire, the mechanical governor would take charge of the engine. On the other hand, when the engine was used for electrical purposes only, no mechanical governor was used. The automatic apparatus by means of which the engine would be slowed or stopped, in the event of the governing wire breaking when speed was being controlled by electricity, was then shown.

Captain Sankey. Captain H. R. SANKEY (late R.E.) considered, in reference to the strictures which the Author had cast on throttle-governors, that he had been misled by comparing the results obtained with a good cut-off gear with those of inferior throttle-governors. In the first place, the throttle-valves described were not suitable for accurate governing, except that shown in Fig. 9, Plate 3, which was the best form, if certain details in the design were attended to, and if the manufacture were equal to that of gauge work. In fact, it was more difficult than gauge work, because the clearance of the plug piston had to be not less than $\frac{1}{1000}$ inch to prevent sticking, and not more than $\frac{2}{1000}$ inch to prevent excessive leakage, which would be detrimental to governing at light loads. The arrangement shown in Fig. 5, in which the compression of the spring had to be transmitted, when balancing the centrifugal force, through a system of links and pins, was a faulty one. At every one of the pins there would be friction, acting either with or

against the spring according as the balls tended to go in or out, and under such conditions it was clearly impossible to obtain accurate governing. The spring should be placed in direct connection with the governor balls without any intermediary. With such a governor and throttle-valve, regulation to within 3 per cent. when the load was changed from three-quarter load, as given in the Paper, to no load, was easy. This was a degree of accuracy which the Author had stated he had obtained with his cut-off gear, and which he considered sufficient for all practical purposes. It was not difficult to obtain regulation to within 2 per cent., and it was possible, although somewhat difficult, to obtain it within $\frac{3}{4}$ per cent. Captain Sankey.

Mr. J. S. RAWORTH remarked, in confirmation of Capt. Sankey's statement, that it was unfortunate the Author had described governors of other classes, that were evidently not the best of their kind, in comparison with his own most highly organised and finished governor. The Willans governor represented a class that had been most successful in combination with the ordinary throttle-valve. Another example of the same class which he brought forward merely as an illustration of the good results obtained by a similar governor, was that made by Messrs. Browett and Lindley, of Salford. With that governor results had been obtained which were comparable to those described by Capt. Sankey. With regard to shaft-governors, that described in the Paper was an excellent one; but he thought praise was due to the excellent governors made in the United States, the efficiency of which, no doubt, resulted from the peculiar practice of building engines in large numbers to the same patterns. He referred to the shaft-governor acting directly upon a single valve. By making those governors in large quantities a degree of perfection had been attained in America which had not been readily obtained in England. The difficulty was not in the manufacture of the governor, but in designing it and in perfecting it under trial. Regulation to within 1 per cent. was attained in every-day practice, and if, therefore, the governor represented in the diagram was regarded as the best that could be made in those two respective lines, that would be to some extent misleading. He had seen the particular governor brought before the meeting at several electric-lighting installations with which he had been connected, and had been struck with the remarkable degree of perfection exhibited in the performance of its functions; it worked indeed so perfectly that he doubted if it could be much improved by adding electrical gear to it. It would be remembered that Mr. Raworth.

Mr. Raworth. Mr. Willans had brought before the Institution[1] a description of an electrical governor, so perfect in theory that disappointment had been felt when expectations of it were not absolutely fulfilled. Possibly the reason for that was that there had been no demand for electric-governing, or that mechanical governors were able to obtain so near an approximation to a constant speed, that it was easy to compound dynamos to the extent of 2 or 3 per cent. above the straight line necessary to make up for the loss of speed, so that in isolated installations electrical governors were not essential. In installations in towns where many dynamos, all shunt-wound, worked in parallel, and under the control of the attendant, the complication would be too serious to be entered upon with a light heart.

Mr. Rigg. Mr. A. Rigg thought the Watt governor was not so bad an apparatus as many people considered, but that shown in the drawing was an extremely bad example, for its balls were not heavy enough, and the design was not in proportion. The action of the Watt governor was that of a non-sensitive governor through an extremely small space. The throttle-valve for all practical purposes might be almost entirely closed, and the engine might still run with nearly full power. So it was only the slight final movement of the governor that regulated the engine, and it should not be said that the balls at the bottom showed one speed, and in a higher position a different speed, for that did not affect the governing action. This governor acted on the engine through a very small space, and fair regulation would be obtained by such a governor of proper proportion.

The question of friction had been raised by Captain Sankey. The Porter governor had two evils in this respect, first, all the stresses of the centrifugal force of the balls were taken through the pins, causing considerable wear and tear. The momentum also of the weight A had to be overcome by the action of the centrifugal force, and that caused resistance akin to that of a dash-pot and detrimental to the quick action of this governor. He offered the same criticism upon the governor shown in Fig. 4. Fig. 5 showed a better governor, for in it there was no heavy weight to overcome as in Figs. 3 and 4. The spring gave a regulation which could not be obtained with a uniform action of a load unless the links were worked, and the regulation was not nearly so good as could be secured by the action of the spring. That governor, however, had the same evil of friction in its pins

[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 166.

that Captain Sankey had alluded to. Fig. 17 showed a better class of governor, and one which he had used for hydraulic engines, with satisfactory results. It was not, however, made like that shown in the Fig. Instead of a spring in the box, there were two springs, one on each side, connected with the balls, so that as the balls diverged they worked the two springs directly, and there was no appreciable tension on the links and levers. It was extremely sensitive, and he knew few governors that worked better. Shaft-governors formed a more interesting subject than all the rest. Fig. 14, he believed, showed the first that had been made by the Author; but the earliest was that patented in 1802 by Richard Wilcox; and the Dods wedge motion, used by the Author in Fig. 12, dated as far back as 1839. As to throttle-valves, all of those in the Figs. had the spindles moving longitudinally, and if there was one thing that should not be done with throttle-valves it was that. The proper way of working a throttle-valve was to turn the spindle round, because the friction was infinitesimal, and it was well to remember that the only way to make a governor work well was to give it nothing to do. With regard to the indicator-diagrams, *Figs. 13* and *18*, although it had been considered that sharp corners at the point of cut-off were essential in all well-arranged engines, that idea was now modified. Sharp corners caused many irregular strains on the engines, and it was better to sacrifice a little of the sharp corners for the purpose of running the engine more easily and of making the changes less suddenly. The perfection of American governors had been attributed to the greatness of the number manufactured. The real reason why they had worked well was that they were properly and scientifically designed. There were two ways in which an engine could be governed by a shaft-governor; one, by the centrifugal force of the balls, and the other by the momentum of the wheel, as in the marine governor. The Moore governor was used by Messrs. Marshalls, of Gainsborough, and consisted of weights, like those shown in Fig. 14, with a fly-wheel, the movement of the eccentric being effected by a combined action overcoming the momentum of the fly-wheel and the action of the levers. It was somewhat complicated, but so far as it went was constructed on scientific principles. The Westinghouse governor combined that principle with the other in a much simpler and neater manner. Taking a weight like that in Fig. 15, by way of illustration, and suspending it as shown, the centrifugal action was that which moved it radially from the centre. If, instead of the weight being suspended where it was, the point of suspension were moved at

Mr. Rigg.

Mr. Rigg. right angles to the position shown in Fig. 15, the weight would act by momentum, and not by centrifugal force at all. If the centrifugal force and the momentum were required to act equally, it would be hung at 45°, if not to act equally then the point of suspension would be at a different angle. All that was needed to make the governor shown in Fig. 15 into a good one, was to enlarge the diameter and move the centre about 45°. It would then act much better than that shown in the diagram.

Mr. Halpin. Mr. Druitt Halpin asked, with reference to *Fig. 16*, in which the Author had drawn lines showing the calculated, theoretical, and actual pressures as determined by experiment, what was the difference between the calculated and the theoretical pressure, and also how that expression came to be used. Governors regulating to within 1 per cent. had been alluded to by the Author. That doubtless was a good result; but it was by no means the best result that had been obtained. In the discussion on Mr. Willans' Paper,[1] read ten years ago, he had shown the original Moscrop diagram from an electric-lighting engine subject to sudden variations of 150 HP., and the total range of variation of speed was one-third of 1 per cent., or one-sixth above, and one-sixth below the normal. That was with a double-acting Knowles governor, in which the length of the rod was changed as in the well-known system adopted by Messrs. Hick and Hargreaves. Much had been said in praise of shaft-governors, and particularly the American governors; he considered that it was good workmanship that accounted for much of their success. With regard to Captain Sankey's remarks on the admirable governor he had shown, he thought that its design tended to reduce friction to a minimum, and to eliminate it altogether as far as the pins were concerned; it was certainly preferable to the system shown in Fig. 9. In dealing with those fine adjustments, it was impossible to obtain good results with the combinations of brass and cast iron as shown. He believed that a great catastrophe had been attributed to that combination in the case of the "Thunderer." He did not see how, in fine work, the relative metallic expansions could be expected to remain proportional, and thus the governors would not always remain free. He had taken autographic Moscrop records of the American governors, and on the same day the same Moscrop recorder had been applied to an English engine that made no pretence to accurate governing, with the result that the latter records were much superior to the former.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 198.

Mr. W. SCHÖNHEYDER agreed as to the advisability of not using a sliding rod through a stuffing-box. It was better to have a spindle which rotated through a small angle, but it was better still not to have a rotating spindle causing friction at all. He believed he was correct in saying that Messrs. Bumsted and Chandler passed the spindles through a piece of indiarubber, so that it only was moved through a small angle, and there was practically no friction. There was no stuffing-box, as the indiarubber served as a means of packing. Mr. Schönheyder.

Sir FREDERICK BRAMWELL, Past-President, expressed surprise that, in a Paper dealing with governors generally, no mention had been made of the governors of the late Sir William Siemens, which, it would be recollected, were admirable in their power, in their quickness, and in their regularity of governing. He was sorry they had not been alluded to. Fig. 14 or Fig. 15 appeared to him to illustrate a shaft-governor which he knew as the Hartnell governor, and which he believed had been exhibited at the Royal Agricultural meeting at Cardiff in 1872. He had a small electric installation at his own house, with an engine running at 240 revolutions per minute. It was fitted, so far as he knew (he had never pulled it to pieces), with a governor of that kind. He had on many occasions tested it by throwing the whole load off the engine when in full work and putting it on again, but he had not been able, with an ordinary watch, to detect any difference in the number of revolutions. Sir Frederick Bramwell.

Mr. J. PHILLIPS observed that the Author had remarked that, "A good governor should be reliable, simple in construction, easy to drive, and instantaneous in its action, both in increasing as well as in reducing the supply of steam. It should not reduce the power of the engine to which it was applied, but should tend to economise steam." He should be glad if the Author would explain how steam could be economised and the speed left constant without reducing the power of the engine. In another place the Author had referred to the power of the engine not being reduced. He was unable to see how the supply of steam could be reduced and the revolutions maintained without reducing the power. He thought the Watt governor shown in Fig. 1 should have been shown in a different form. The original Watt governor was made with cross-arms above the point of suspension of the ball arms, and the sleeve had considerable motion. Fig. 1 exhibited an ill-constructed form of Watt governor. A properly made Watt throttle-valve should be turned. Many throttle-valves were not true, and could never work satisfactorily; and Mr. Phillips.

Mr. Phillips. some failed on account of the valve being out of balance. He was surprised that the Knowles governor had not been referred to. It had a supplementary high-speed governor, used to adjust the length of the rod connecting the throttle-valve with the governor-lever. In order to get an engine with any governor to run at a uniform speed, it was absolutely necessary that the throttle-valve should be adjusted to admit the correct amount of steam.

Dr. Preller. Dr. Du Riche Preller asked whether the Author was acquainted with the Thury automatic electrical regulator which, in principle and in its mode of action, by constant rotary motion, was similar to that exhibited by the Author. The Thury regulator, of which he had given an illustration and short description in a Paper on the Mont Salève Electric Rack-Railway,[1] was extensively used in the central stations erected by the Société de l'Industrie Electrique of Geneva, notably in Switzerland, France, and Italy, where he had frequently had occasion to observe its working. This system of automatic regulation was applied in two ways. One was in connection with separately-excited dynamos, in which case a shunt of the main current passed through the solenoid, and the consequent varying rise and fall of the armature bar was transmitted by electrical contact, and then by a friction-bevel mechanism and worm-gearing to an arrow acting on the contacts of a rheostat connected with the compound-wound exciter-dynamo, the excitation being thus automatically varied. The other method was in connection with turbines and steam-engines, the solenoid replacing in this case the ball governor, while the armature bar was connected with two unequal pistons and a slide-valve in conjunction with an oil dashpot to ensure stability. This last-named mechanical direct-acting regulator was that of Messrs. Fæsch and Picard of Geneva, who had designed the hydraulic machinery for the power-station of the Niagara Falls Power Company. This combination of electro-mechanical regulation was at once sensitive and instantaneous, the variations of speed not exceeding 1 per cent. when half the load was suddenly taken off. Constant speed of the exciter-turbine or steam-engine of the Thury automatic electric regulator was presupposed for the effectual action, otherwise the regulation was liable to come too late, the more so as the pressure of the bevel surfaces against each other did not always take instantaneous effect. These two defects he had frequently had occasion to observe, and the Author's regu-

[1] *Engineering*, vol. lvii. 1894, p. 438.

lator would be equally subject to them. At all events it would be interesting to know which of these two electrical regulators was first in the field. Dr. Preller.

Mr. DAVID JOY had been working on governors of marine engines, having in view the possibility of making a governor which should anticipate the movements of a ship in the sea, and so preclude the possibility of steam being shut off too late or admitted again too early to prejudice adequate regulation. When the steam was put on as the ship fell back into the sea there was a lash on the screw, which was often the cause of the fracture of screw-blades, or even the shaft. He had taken up the matter of his anticipatory governor after the accident and terrible experience to the s.s. "Paris"; and when recently developing a new fluid-pressure reversing-gear, he had devoted his attention to the subject, because he saw that this gear was amenable to rapid and delicate control. His first efforts had been successfully made upon dynamo machines. He did not propose to dwell on the marine aspect of the question, but would refer to what had been lately done on the subject of controlling dynamo engines, so far as he had been connected with the question, and so far as his knowledge went. The governor he was about to describe was a joint invention of himself and Mr. Kadolitsch, Engineer-in-Chief of the Austrian Lloyd Steamship Company. As he had said, his fluid-pressure reversing-gear lent itself most readily to control. It acted through the interference of the movement of the fluid which actuated the eccentric to and fro. A touch of the finger against the pipe would control the fluid, and give more or less steam as desired. The engines hitherto built were single tandem-engines, compound, driving dynamos direct, and were constructed of powers up to 300 HP. on the Continent. In England some of the same kind were being commenced. The eccentric was fitted on the shaft, giving a range from full-gear to mid-gear. The fluid was conveyed into the pipe by a small pump driven by the engine, so that, as the engine was in motion, there was a continuous flow of fluid, which passed round a circuit and through a small reservoir. On that circuit was situated the connection with the pipe passing to the eccentric to control it, so that the pressure that controlled the eccentric was a differential pressure, the fluid being pumped round the circuit and through a small valve, which passed it either back into the pump, or into the eccentric, and it depended upon more or less being passed to the eccentric whether less or more steam should be admitted to retard the engine, or to give it fuller Mr. Joy.

Mr. Joy. play. That control was effected by a solenoid. As the engines were connected directly to the dynamos, the engine and dynamo formed one piece of machinery. But connected with the dynamo was the solenoid, which actuated the small valve to which he had referred. If more or less electricity was produced than was required, the small valve controlled the fluid, and either admitted more fluid to the eccentric, so as to cut off the steam, and so the power, or let the fluid pass away back to the pump, and the eccentric falling to full gear, the speed of the engine was increased. The results obtained from the arrangement showed that with the engines running at 210 revolutions per minute, full power might be reduced to one-fifth of the power, with a variation of only one revolution either way—that was, ½ per cent. in the total revolutions. That was found, however, to be too quick, and was too sensitive to be useful; and now the governors were speeded so as to take 5 revolutions, or 2½ per cent., to pull the engine up to mid-gear; but it could be set for anything between ½ per cent. and 2½ per cent. The details of the engines were upon the table and could be examined by the members.

Dr. Hopkinson. Dr. JOHN HOPKINSON remarked that the first point he wished to raise had reference to the results shown in *Fig. 16*. A discrepancy or a difference had been found by the Author between the theoretical results which his calculation gave for the strength of a certain spring in one of his governors, and those which he realised in practice. The recognised laws of centrifugal force were of course nothing less than a particular department of the recognised laws of motion; and a discrepancy between those and the results of observation would either imply some incompleteness in the method of applying the recognised laws of centrifugal force or some errors of observation. He considered that the point was one which required a little further elucidation. The other point to which he wished to refer related to the electrical control of steam-engines. It had rightly been pointed out by the Author that electrical control could be such as to give a constant potential at the dynamo-machine, or, if it were preferred, a constant current delivered by the machine. For a constant potential at the dynamo-machine a high resistance solenoid was used, connected between the two terminals of the machine. For a constant current a low resistance solenoid was used, and the whole current, or a definite portion of it, was passed through. It had further been pointed out by the Author that the speed of the engine could be regulated by the difference of potential at various parts of an extended system,

and he proposed to do that by bringing back the pilot wires in the well-known way from the more distant parts. He would merely point out that that was not necessary. It was possible to compensate for the loss of pressure by the resistance of the leads in other ways. Use should be made of the high-resistance coil connected between the terminals and the dynamo, and another coil should be wound round that coil to carry either the current or a proportional part of it a definite number of times depending upon the resistance of the circuit. It was taken in that direction to demagnetize in part the effects of the first coil. If those two coils were proportioned aright, a definite action of the electromagnet would be obtained at the time when the potential at the far end of the conductors exceeded or was less than a certain assigned value. Dr. Hopkinson.

Mr. HERMANN KÜHNE observed that the Author had set himself the task of describing a number of governors that met the demand for close regulation, some as types to be avoided, others to be imitated. Dealing exclusively with mechanical regulation, he found that the Author had mentioned ten governors. Two of them, the Watt and the Porter were well known, and of the remaining eight five had been designed by the Author. It had been stated by the Author that a governor should have great lifting-power, forcing-power, and stability, and that the Watt, Porter, and Buss governors had not sufficient stability, while, for instance, the stability of the governor, Fig. 5, was very great. Again, with regard to the same governor, the Author had stated that with only 4 per cent. increase in speed it overcame a pressure of 200 lbs. He thought there was some confusion in terms, as the stability of a governor was quite distinct from its power. A governor of great stability might be deficient in power, and a powerful governor might be devoid of stability. The meaning of "stability" should therefore be explained, or the term should be eliminated and replaced by others that conveyed a distinct meaning. The Watt governor would require, as the Author had correctly observed, a great increase in speed to open it through a large angle. Nevertheless it had very little power. That resistance to follow the increase in speed the Author had called stability, and thus ascribing to it stability which, in other parts, he denied the governor altogether. He thought it would be well to adopt the term "static" as descriptive of the sluggish behaviour of governors, as adopted by eminent writers on the subject. A governor was called "static" if it only answered after a great increase of speed. That was a very convenient term, as there Mr. Kühne.

Mr. Kühne. was also the corresponding term "astatic" used to describe opposite behaviour of the governor, as the Author had used it in regard to Fig. 4. The term "astatic" for that behaviour would be more suitable than the term "isochronous," used by him, because the latter word indicated that the angular opening of a governor would be the same for every equal increase in speed. As the Author had correctly observed, the astatic governor, was useless as it flew through its whole range at the slightest provocation. The proper behaviour of a governor, so far as sensibility was concerned, was called "pseudo-astatic," or very nearly astatic; the nearer a governor approached "astasy," the smaller would be its regulating interval, viz., the increase in speed required to bring the governor from its lowest to its highest position. That static or astatic behaviour of a governor was, however, quite independent of its power, or, as he preferred to call it, energy. The energy of the governor was dependent on the masses held in suspension, whether those masses were represented by dead weight or spring load. That accounted for the smaller energy in the Watt governor, in which the balls themselves were the only masses in suspension, and at the same time explained why a loaded Watt or Porter governor developed more energy. A spring load was more effective still, because it permitted of a great power in a comparatively small space. The power required to compress a spring was also confused with the regulating power or energy of a governor. It had been stated by the Author that the governor, Fig. 5, with a change of 4 per cent., had a lifting- and a forcing-power of 100 lbs. That was an impossibility for a governor having balls revolving at a radius of 4 inches and 8 inches respectively. If a spring governor were revolved at a constant speed, the balls would diverge, and the centrifugal force would balance that of the spring. Although there might be at such a moment a pressure of hundreds of pounds upon the spring, none of it was available for regulating purposes except when the speed varied, and then it only amounted to the balance between the two forces. With regard to the governor, Fig. 17, the late Dr. Proell had made calculations from its dimensions, and the result had been that at the lowest position, with a variation in speed of 2 per cent., the governor developed an available regulating energy of about 6 lbs., in the mean position about 11 lbs., and in the highest about 15 lbs.; also the governor would begin to open at 266 revolutions per minute, would take up its mean position at 295 revolutions, and its highest position at 312 revolutions; so that there was a total regulating interval of 17 per

cent. in the governor. As compared with the Author's statement, that the governor overcame a further pressure of 200 lbs. with a variation of 4 per cent., there was a wide discrepancy. Returning, however, to the governor shown in Fig. 5, he had been astonished to find it stated in the Paper that the Author had introduced not only that form, but the straight path of the balls in 1869. Perhaps the Author would indicate where that particular form of governor had been introduced. The other form, Fig. 12, was the only approach to it which had been published; but no reference had been made in any description of it to a straight path. Under those circumstances, it could not be said that the Proell weight-governor was a variety of that shown in Fig. 5. He considered that the Author's statement that the action of the balls was similar was erroneous. With reference to the date of the introduction of the Proell weight-governor, showing that it was 1871 and not 1884, he had placed on the table a signed patent drawing bearing the former date. With regard to the lifting- and forcing-power, these seemed to the Author to be two distinct qualities of a governor, whereas they were identical, seeing that every governor exerted the same power in rising at 2 per cent. increase of speed as it did in falling on the same decrease of speed. He preferred to call that lifting- and forcing-power energy. The form of governor which the Author had illustrated was a special one, used in connection with the Proell expansion apparatus, and comparatively few had been made. Tens of thousands were, however, in use of the form shown in the patent drawing, or a slight modification of it. He wished to append the following Table of performances of the Proell governor:— Mr. Kühne.

LIGHT WEIGHTS.

Weight of governor . . lbs.	43	72	120	170
Lift of sleeve . . . inches	$1\frac{5}{8}$	2	$2\frac{5}{8}$	$2\frac{3}{4}$
Energy at 2 per cent. alteration of speed . . lbs.	1	2	3	4
Revolutions per minute . .	120	100	90	80

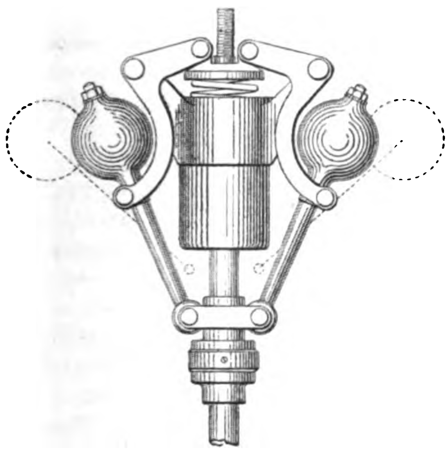
HEAVY WEIGHTS.

Weight of governor . . lbs.	80	108	170	240	260
Lift of sleeve . . . inches	$2\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{1}{4}$	$3\frac{1}{4}$
Energy at 2 per cent. alteration of speed . . lbs.	2·6	4·0	5·0	6·8	8·6
Revolutions per minute . .	145	130	115	107	120

Mr. Kühne. The above governors had also been made with four balls, having an energy as great as 56 lbs. at 2 per cent. variation. As an advantage of those governors, it should be noted that that energy was developed at a moderate speed. For an alteration of speed of 4 per cent. the energy was doubled, and for 1 per cent. halved. He did not think that for a weight-governor that regulating power should have been called "practically nothing." For equal size the Proell weight-governor had about twice the energy of, for instance, a Porter governor. It had been further stated by the Author that the Proell governor required a dashpot. Apparently he meant an air- or oil-brake, as by a dashpot was usually understood a cylinder with a piston to prevent shock. First of all, the Proell governor needed a brake only under special circumstances where its sensitiveness would be too great. He did not think that 10 per cent. of all the Proell governors were provided with a brake of any kind. He could not agree as to the purpose of a governor brake. Let a governor having a total regulating interval of 2 per cent. be considered to be applied to an engine that was not quite balanced or that had a light fly-wheel, then the inherent differences of turning the engine might be larger during every stroke than 3 per cent., and the engine would cause the governor to hunt. At the beginning of the stroke there was the full impulse, at the end the momentum was spent, but in the meantime the sensitive governor had passed through its whole range. As the Proell expansion apparatus had been originally designed for application to old engines, such occurrences had to be guarded against, and that was the reason why its governor was once for all supplied with what the Author had called "something in the nature of a dashpot," which, however, experience had proved to be the most efficient air-brake that could be devised. With good workmanship air-brakes of that kind would almost prevent the governor from rising with any increase of speed if the air-screw were quite closed. Between that and the air-screw quite open, it was easy to find a medium position, such that the governor was prevented from following the impulses of the engine too quickly, and was kept in position until a new impulse could be given. A perfect governor should, the Author had said, require no dashpot. That statement conveyed no meaning, as no governor would answer every condition. To place a governor with 1 per cent. regulating interval on an engine, driving, for instance, stone crushers, would not be proper. The finer the regulation was intended to be, the more astatic the governor must be made, but the greater was the need for an efficient brake. A

static governor, such, for instance, as had regulating intervals of 17 per cent., could regulate a badly-balanced engine without a brake, because it was indifferent to slight variations. He could not agree in the statement that air was a less effective medium for governor-brakes than oil. The brake should not stop the freedom of the governor, but only restrict it. A spring had even been interpolated, as in the Buss governor, between the governing lever and the oil-brake to produce an elastic motion at that point, and the finest regulation was the result as nearly astatic governors could be used without fear of hunting. It was evident that a brake that used an elastic medium like air, and that did not require such spring, was preferable. If the Author had used Mr. Kühne.

Fig. 29.



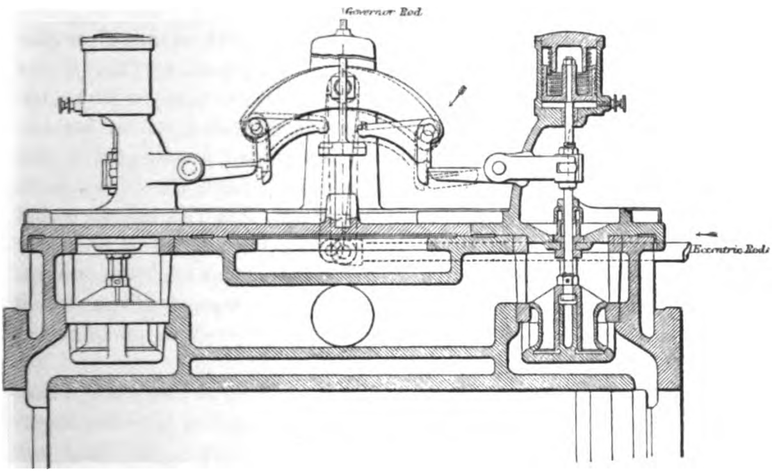
oil-brakes, such as he had illustrated, with stuffing-boxes at the top, he could understand why he had such a bad opinion of dashpots. The stuffing-box was useless, as the oil displaced on the top would be drawn in by the pipe to the bottom. He would, however, mention that the Proell weight-governor was no longer used by Dr. Proell's licensees, not because it was a bad governor, but because the Proell spring-governor, while retaining the fine astatic properties of the old form, gave about three times the energy for the same weight. The specimen exhibited, *Fig. 29*, weighing about 2 cwt., developed an energy of 21 lbs. for an increase of 2 per cent. in speed. A Porter governor, to give out the same energy, would weigh ¾ ton. The power required to compress the spring when the balls were quite

Mr. Kühne. open was 1,781 lbs. He did not, however, consider that as regulating power. In the governor exhibited was introduced for the first time the straight path, which the Author claimed for so many of the governors described. That important property, however, not only gave excellent regulation in connection with such an arrangement of spring as Dr. Proell had designed, but also enabled the governor to work in any position. He did not think that the best results would be obtained in working the governor shown in Fig. 17 horizontally, because the influence of gravity was not eliminated in any governor with rising and falling balls. He did not understand the Author's meaning that a throttle-valve reduced the power of an engine, for that was only possible if a throttling engine was furnished with a throttle-valve of too small steam-passage. All important factors, such as size of ports, laps of slide, throw of slide being equal, the throttling engine must give out the same power as an expansion engine, if the throttle-valve were fully opened by the governor, so that the passage for the steam through it was equivalent to the size of the ports. If that were not the case, the throttle-valve was too small. With reference to the indicator-diagrams, *Figs. 13*, *18*, and *21*, he thought it detracted somewhat from their value that no atmospheric line nor scales had been given. It was impossible to check the diagrams under those circumstances, and he, therefore, would only express an opinion about *Fig. 18a*; to obtain which there must have been exceptional phenomena in the cylinder. The only conclusion was, that there was condensation and re-evaporation. Although he agreed that the double-beat valve was the best for the purpose, he took exception to the statement that the power to work them was insignificant, and that the steam-pressure was irrelevant. A valve to work with a 5-inch steam-passage had, for instance, an unbalanced surface of 4·3 square inches. It would, therefore, with 50 lbs. per square inch, require a pressure of 215 lbs. to detach it from its seat, while with 120 lbs. per square inch it would take 516 lbs. He could not share the opinion that the variety of the Sulzer gear, shown in Figs. 19 and 20, had any advantages over the original or over many other gears, in which he thought he might include the Proell gear, which was represented in the model on the table. There were no less than nine points of friction which had to be acted upon by the governor, before an alteration in the expansion could take place in the Robey gear, whereas in the Proell gear there were none.

It would be seen that at the point of the opening of the valves the vertical part of the bell-crank B, *Fig. 30*, pressed upon its

lifter and opened the valve at a time when the tail-end of the bell-crank was not in contact with the tripping-pad of the governor-rod; therefore, the pressure required to open the valve could in the Proell gear be neglected, because it was given out in a positive manner by the engine itself and could not re-act on the governor. When the valve was once opened, it was balanced, with the exception of the slight pressure of the closing spring. The governor in the Proell gear was therefore perfectly able to effect a variation of the expansion even during the stroke, because the governor was free to move and would trip off the valve at any point when the tripping-pad and the tail-end of the bell- Mr. Kühne.

Fig. 30.



crank met. In the gear shown on the Author's cylinder it was admitted that the fulcrum of the valve-lifters was pushed down and so held rigidly in position, the movement of the fulcrum (upon which the alteration of the expansion depended) having to take place during the interval when the valve was not being lifted. He thought that was a disadvantage of the Robey gear. Supposing that such an engine worked for a time with an average cut-off of five-eighths; then the engine would be under the control of the governor only for three-eighths of the time, and the governor would be blocked for five-eighths; if then an alteration of load took place at the beginning of a stroke, the governor would be blocked and could not respond to the altered speed until a cut-off had taken place at the full five-eighths of the

Mr. Kühne. stroke, whereas, perhaps a cut-off of only one-quarter had been required; if the governor were at all sensitive it would, on its release, fly wide open, and then very likely admit less steam than would be required for the return stroke, because, at the moment when the valve opened, the action of the governor was again eliminated until the valve became once more released. It was therefore evident that any but a very static governor, if controlling such a gear, would be sure to hunt, while on the other hand a static governor was useless for close regulation.

That it could be put out of action by a cord had been stated by the Author as an advantage of the Robey gear; but he did not consider that a desirable or reliable means for the purpose. If, for instance, a cord were carried to every room of a large cotton-mill, there would be required such a length of sagging cord, running over many pulleys, that it was difficult to imagine that such a scheme had ever been carried out in practice. The Proell gear lent itself easily to the application of an electric stop-gear. If by means of an electric current the armature of an electro-magnet were attracted, a catch could be released, a weight dropped, and the tail-ends of the bell-cranks raised so high that they could not come into contact with the valve-lifters and the valves would remain closed. This scheme had the advantage of being perfectly reliable, and had been carried out in many instances with perfect success; the electric wires could be led anywhere, and the use of elastic cords and pulleys could not be compared in certainty of action with this arrangement.

The question of governing engines was of such importance that he thought the Institution should take it in hand. The Royal Agricultural Society had arranged tests of steam-, gas-, and oil-engines, to the great advantage of those industries and the agricultural interest. He ventured to submit that the engineering and manufacturing communities had an equal interest in seeing the question of regulating engines settled by competitive tests, under rules laid down by the Institution and under its control.

Prof. Unwin. Prof. W. C. UNWIN said the subject under discussion was one of so much complexity that he should have been glad to escape the necessity of speaking on it. The Author clearly had had considerable experience in the use of various governors, and he had brought forward some of his conclusions from practical experience in the Paper. It was only fair to point out that while the Author had put forward some very definite conclusions, he had often failed to give any reasons

Prof. Unwin.

for them. Taking a single instance, the Author, in referring to a governor with an air-dashpot, said that no dashpot ought to be worked except with incompressible fluid. That might be true or not, but no reason was given for the statement. He thought the Author was not very well acquainted, or had not cared to show that he was acquainted, with a good deal that had been written on the subject. On p. 212 he had mentioned an exceedingly valuable Paper by Mr. Ransom, on an experimental investigation in which the true action of the governor was determined by exact observations. There were three Papers[1] by Mr. Ransom, and the one quoted was perhaps not the most important. The Author had also quoted a Paper in the Proceedings of the Institution by Prof. Dwelshauvers-Dery. There were three Papers by that gentleman, and in addition to that, there had been a later investigation published within the last year under the title of "The Dynamical Study of Steam-Engines."[2] The Author had first mentioned the Watt governor, and stated that, although it might prevent an engine running away, it had really no regulating power. In one of Mr. Ransom's Papers an account was given of experiments with six or seven of the most reputed governors—the Porter, the Buss, the Pickering, and others, and it appeared from the results given that the only governor of the whole series which really gave a trustworthy regulation was the old Watt governor. He did not wish to draw the universal conclusion that the Watt governor was better than all the others. He merely said that the Author's statement that the Watt governor had no regulating power was put much too positively. In Fig. 4 the Author had shown a governor which he said he had designed about twenty years ago. In looking at it one recognised what at any rate was very commonly described as the Farcot governor. He did not positively know at what date that governor was first used by the inventor, but it was described in Callon's "Cours de Machines," published in 1875, as a well-known form of governor. He therefore suspected that it was earlier than the "twenty years ago" which the Author had mentioned. The ordinary throttle-valve with a disk pivoted in the centre had been referred to by the Author, and he said that it was simple in construction and easy to move. He had no doubt that when it was

---

[1] Minutes of Proceedings Inst. C.E., vols. xcviii. cix. and cxiii.

[2] "Étude expérimentale dynamique de la machine à vapeur," by Prof. V. Dwelshauvers-Dery, published by Gauthier-Villars et fils, Paris, 1894. Also Minutes of Proceedings Inst. C.E., vols. xciv. civ. and cx.

Prof. Unwin. first used it was supposed to be a balanced-valve, but it was not a balanced-valve, and was not easy to move except in very small sizes. The action of fluid rushing past an oblique plane showed that nearly all the pressure was concentrated on the anterior edge, and that there was very little pressure on the parts which were more sternward. The ordinary throttle-valve was not even approximately a balanced-valve, and except in small sizes, it was not easy to work. He supposed it was from that that some of the difficulty had arisen in using an ordinary governor with small effort in working an ordinary throttle-valve. The Paper as a whole was no doubt a plea for the use of automatic governing. No criticism was considered by the Author too severe for proceeding in any other way, although it had been known for a long time that the economical advantage of automatic governing had been in general much exaggerated by engineers. In the majority of cases there was no doubt an economical advantage, but it was usually only a small one. He supposed that from the greater beauty of the mechanical arrangement, automatic governing would probably be the most largely used, but he was persuaded that the economical advantages had been greatly over-rated.

With regard to the special problem in governing the speed of an engine, there were two sets of causes of fluctuations of the speed. There were causes which could be classed as periodic, occurring within the time of a revolution, and causes which were aperiodic. So far as the periodic causes of variation of speed were concerned, a governor could have no action whatever. The governor could not regulate the engine within the time of a revolution, and it was the fly-wheel alone that must be depended upon to neutralize to a large extent those periodic fluctuations of effort, and as far as possible to remove them from having any effect upon the governor. They resulted, of course, from the variation of the steam-pressure in the stroke, and from the variation in position and velocity of the working parts of the engine. With regard to the aperiodic causes of fluctuation of speed, the fly-wheel also had a very important function. It could not prevent the fluctuations of speed due to those, but it could make the variations so gradual that it was possible for a governor to control them. He did not believe that any consideration of governors was valid if it did not proceed with the simultaneous examination of the action of the fly-wheel and of the governor. As to the governor itself, it was troubled first by the circumstance that it could only have effect on the regulation of the engine during the period of admission of steam, which was

only a fraction of the revolution, and next, that in proportion as it was made sensitive, and capable of sensitively regulating the speed, its power of overcoming the frictions and so on, which could not be altogether avoided in any form of mechanism, was reduced. There was one type of valve-gear which could be extremely well controlled by any good form of governor. Any form of trip valve-gear could be controlled by a governor, so as to produce very considerable accuracy of speed; but in regard to any other form of valve-gear, in which the governor must exert more or less considerable effort in effecting the regulation, he thought the problem was one of great complexity and intricacy. He would only say that apart from engines using trip valve-gears, he believed the real solution of the problem of governing accurately lay in the use of the relay. If the governor be regarded as a pure thinking machine, and threw all the work of governing on some relay, there was a possibility of securing any accuracy of speed that might be desired. He might be told at once that relays had been tried over and over again, and that they had one universal fault of hunting. That was perfectly true of a great many relays that had been used. The relay had been used in a great many cases without any insight into one of the conditions absolutely necessary if relays were used at all. In most forms of relay regulation which had been used, the governor started the relay, and the relay went on acting without any control till, by the alteration of the position of the governor, it was thrown into action in an opposite direction. It was impossible to avoid an extreme form of hunting with a relay governor of that kind. If a relay were used at all, it should be used much in the form in which it was used in the steering-gear of a ship, where the captain turned a small wheel which gave the signal to the relay to get into action; it also told the relay to do so much and no more. The relay came to a stop when it had turned the rudder over to a certain small extent. The captain then considered whether enough had been done; and if not, he gave a further signal, and the relay did a little more. It was only when the relay was used in that form that it could properly control the speed. Governors of that type had been used—hydraulic and ratchet relay-governors—to control large sluice-valves of turbines with remarkable accuracy. These turbines were used for driving dynamos in electric-lighting installations, where the load was necessarily varied. The dynamos ran with great regularity of speed, and the whole secret was, first, that the force required to do the regulation was thrown entirely upon the

Prof. Unwin.

Prof. Unwin. relay, and, secondly, that the relay was of the steering-gear type. It had been stated that if a relay-governor of the steering-gear type were used it could not be isochronous. In general it was not desirable that a governor should be isochronous, but it was possible that a relay-governor could be virtually so if necessary. The automatic action of the relay in coming to rest after being started by the governor had been made also to readjust the position of the point of suspension of the governor arms. Thus, if the speed of the motor increased, the governor height diminished, and the relay was started. As the relay acted, it automatically came to rest again, and simultaneously corrected the error of governor height.

Mr. Swinburne. Mr. James Swinburne said, with regard to what had been called the power or the energy of the governor, it seemed to him that the principles of mechanics should be looked to. In the case of a rotating governor, which compressed a spring with a certain force, any increase in speed must give a certain increase of that force on the spring; and the result was that, whatever form of governor was used, if there were 1 per cent. increase of speed, it would give 2 per cent. increase in the force on the spring. The force on the spring, the force lifting a controlling weight, or whatever it might be, was not, of course, the only factor. It was necessary to consider the distance through which that force could be applied when the governor moved as far as it would, in spite of the opposition of the valve-gear, and see what energy could be obtained in that way. In comparing different governors, such as those in Figs. 1 and 4, it was not fair to put everything down to the form of governor. It should be remembered that the governor in Fig. 4 was revolving much faster than that in Fig. 1. If the latter were driven fast enough, and loaded with a spring, it would give a great "effort"—a very good term to use, "energy" and "power" having other meanings. In making calculations as to centrifugal force in governors it must not be assumed that a ball acted as if its mass were concentrated at its centre. Perhaps some such inaccurate assumption had led to the discrepancies observed. He should like to accentuate the remarks of Professor Unwin on the question of relays, with which was largely involved the question of the hunting of governors. No one before Professor Unwin had pointed out the difficulties arising from governors tending to hunt. The governor might be made isochronous, or it could be designed in the other direction, like the Watt governor, Fig. 1, so that there was a very large variation of speed needed to produce any considerable variation in the position of the balls, or

Mr. Swinburne.

it could be made a compromise between the two. Even when it was intended to make an isochronous governor, it was made not quite isochronous. An isochronous governor obviously would give very little effort. Therefore, in working with it, it was necessary to have some form of relay. A non-isochronous governor, on the other hand, as pointed out in the Paper, would not regulate perfectly with regard to speed, because with different loads it had to be in different positions to control the steam perfectly, unless, of course, it was worked as a relay. But any governor, such as Fig. 1, working with a relay, at once became an isochronous governor if the distance through which it had to move was made sufficiently small. A relay-governor did not necessarily mean a governor that hunted. The other extreme might be reached, and what he had previously called a "hit and miss" governor be used.[1] It could be so made that if the speed were the least above the normal there would be no steam at all, and if the least below there would be full steam. That, of course, was used in the gas-engine, but the difficulty there was that the engine speed varied with every stroke of the piston; there was a jump, as in the case of the gas-engine, and in many cases such a system would be useless. But if an engine were small and fast enough, that no longer held, as, for instance, in the Parsons engine. When steam was admitted the engine was fully loaded; when it was not fully loaded no steam at all was taken. The method gave an efficient engine and very perfect governing, but the system obviously could not be applied to an ordinary steam-engine, and relays must then be employed. A following relay or steering-gear relay might be employed, but that would only work on a governor of the type of Fig. 1, which was not isochronous. A steering-gear relay could not be used with an isochronous governor; therefore, for a following relay a governor which did not control perfectly as to speed must be employed. The difficulty had been solved in the Knowles system, in which two governors were used, one a non-isochronous governor, and the other a secondary governor to alter the valve-gear in such a way that the non-isochronous governor worked at its normal position, and therefore at its normal speed. There was no reason for using a double governor for such a purpose, and he had seen in France a single governor which did the same thing. It might be called a Watt governor, acting directly on the valve; but immediately it moved from its normal position it also put into gear a screw

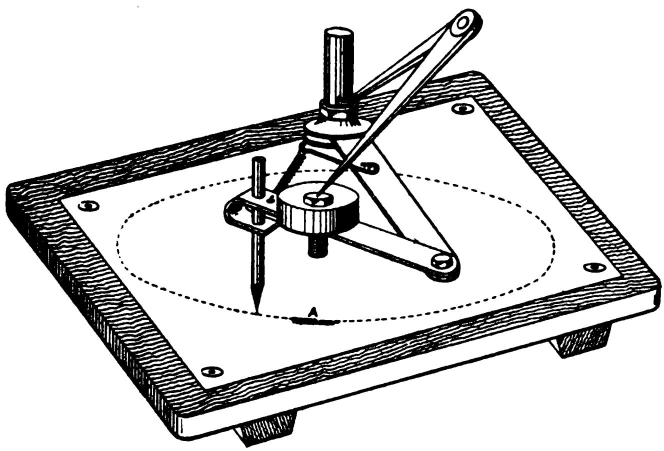
[1] British Association Report, 1894, p. 758.

Mr. Swinburne. and catching relay of small dimensions that altered the length of the valve-rod, until the governor, in spite of the large variation of load, still controlled the engine at its normal position. In reference to dynamos, a question often arose as to whether the engine should be controlled by the torque. The idea was that if an engine were controlled by the output of a dynamo it was controlled before the variation took place. But if that were carefully examined, it would be found that the system was in unstable equilibrium. A governor could not be made to control in that way only; it must also have a speed or an electrical pressure component. With reference to the compound-wound solenoid as a means of overcoming the necessity for a pilot-wire, he remembered being exceedingly pleased in 1887, when he thought he had invented it; indeed, he felt very proud of it, until he found Dr. Hopkinson had invented it before him in 1882.

Mr. Wingfield. Mr. C. H. WINGFIELD observed that the Author had stated, with reference to Fig. 5, that "the lengths of the arms are so proportioned that the balls diverge in nearly a straight line for a considerable distance." He should like to ask the Author why that was advantageous. He supposed it was because this motion was owing to the point of suspension being at infinity. It had been stated by the Author that all attempts to give stability to a governor, by means of a dashpot, were but expedients to minimize an evil, which might and could be entirely eliminated, and he appeared to consider 10 per cent. as a fairly good result when governing without a dashpot. By adding a dashpot to a very simple form of spring governor Messrs. Thornycroft had been able to govern electric-light engines to within 3 per cent., even when all the load was thrown off. He thought, therefore, that a dashpot was a very good way of "minimizing the evil," if it were properly applied. A valve had been recommended by the Author which came down on its seat and shut the steam off entirely in that way in preference to a valve which was free to move a little further while keeping the passage still closed. If the engine suddenly began to race and the valves were shut down sharply and enough steam was left in the chest to increase the speed still further, a very strong spindle would be necessary with a powerful governor; in fact, the parts generally would have to be a good deal heavier than they needed otherwise be. A strong spindle required a large stuffing-box and caused greater resistance, and therefore an increased liability to hunt. Although the Author preferred the dead-beat valve there was still something therefore to be said for

the other. It was interesting to learn that with a governor which acted by shifting the eccentric the speed increased before settling down, but that, with a governor acting on a throttle-valve, it decreased before settling down. It would be well to know if that were generally the case, and if in all forms of expansion governors the speed increased before settling down. Another point which he had some difficulty in agreeing with had been slightly alluded to by Dr. Hopkinson. The positions of the weights and the strength of the springs had been stated by the Author as not working out strictly according to the recognized laws of centrifugal force. In *Fig. 16* the theoretical radial force was shown by straight dotted lines, which, if produced, all converged to a point Mr. Wingfield.

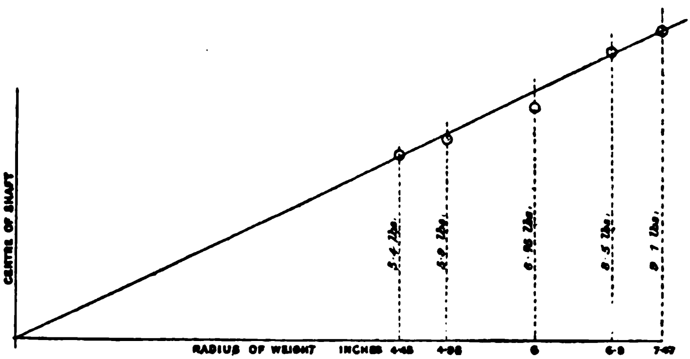
Fig. 31.



about 4½ inches to the left of the figure. The full straight lines came to a point considerably to the right of this. Of course, where they came to a point there was no centrifugal force, and this would be the case if it were possible to place the balls at the centre of the spindle. If the black lines were correct, however, there was a second position—when the balls had diverged about half their maximum distance—at which there was no centrifugal force. He thought there must be some mistake in the observations which gave such a result as that. He had that afternoon made some experiments with a small apparatus, shown in *Fig. 31.* It consisted of two light arms jointed together, one of which carried a weight representing a governor ball, the other having a spindle by which it could be attached to the chuck of a drilling-machine

Mr. Wingfield. and caused to rotate at a constant angular velocity. When it was spinning round the weight tended to fly out, a tendency which was resisted by a spiral spring, the position of which could be so adjusted as to allow the weight to stand at different distances from the axis. He desired to measure the force acting in a direct line between the spindle and the centre of gravity[1] of the weight and arm, and the radius of the circle in which the weight was revolving at the moment this force was exerted. For the latter purpose he attached a pencil to the movable arm carrying the weight, and on the table of the drilling machine a piece of paper was placed. The apparatus was gradually lowered, while revolving, until the pencil made a scratch upon the paper. In some instances several scratches were exactly over each other, and in others they varied about a quarter of an inch as at A, *Fig. 31.* With a pair of hermaphrodites he was enabled, after the

Fig. 32.



machine was stationary, to measure the radial distance by placing the pencil on the spot, or on the mean position of the spots, it had made on the paper when it was running. To measure the force he attached a piece of string to the bolt by which the weight was fixed, and, by a spring-balance to which the other end of the string was fastened, he stretched it in a radial line, passing through the centres of the weight and of the spindle, till the pencil was again over its marks when the load on the balance was then read off. This was a very rough experiment, but he was surprised to find how accurately the results plotted on a straight line, *Fig. 32.* He was not, however, surprised to find that

[1] The position of the weight was such that its centre of gravity and that of the arm were coincident, and were at a radial distance from the axis approximately equal to the radius of gyration.

the straight line ran in a similar direction to the dotted line in *Fig. 16*, and had no resemblance to the full lines. It intersected the base at the centre line, which represented the centre of the spindle. One of the spots fell off the line, but four others were practically upon it. He hoped the Author would explain the way in which the position of the black lines had been determined, and also how the experiments were arranged which appeared to confirm them. Mr. Wingfield.

Mr. Richardson. Mr. J. RICHARDSON, in reply, before dealing with the criticisms in detail, said that there had been probably no fewer than fifty governors invented every year for many years past, and that, as the Paper referred to the past twenty-five years, it was manifestly impossible to mention more than a very small number of those inventions. To these circumstances alone must be attributed the fact that certain governors mentioned by various speakers had not been referred to at all. He had therefore confined himself to such classes as had come under his personal observation. Referring to Captain Sankey's remarks, he was so far in agreement with him, that he recognized the advantage of simple throttle-valve governors under certain conditions, but none of them gave results equal to an equilibrium valve-gear combined with a good governor, and none that he had tested were equal to a plain slide-valve combined with a good shaft-governor. He admitted that there were many good points about the valve, Fig. 9; but, as had been rightly stated, if the cover on this valve be too small by $\frac{1}{1000}$ inch it would be too tight, and if too large by $\frac{1}{1000}$ inch it would be too slack. That being so, he saw no reason why such a valve should be used when there were others which would do quite as well and did not depend upon such extreme accuracy. The production of such accurate work was quite easy, but he did not consider it good engineering to design machinery in which such close work was essential to its success; and any piece of machinery which became imperfect or useless when it was worn to so small an extent, was not nearly so well suited to ordinary use as that in which a wider variation was permissible without interfering with its efficiency. With regard to the percentage of variation in governing, he would like to say that any record of a few minutes' or a few hours' test of the regularity of an engine indicated very little unless all the conditions were known. There were many governors and valves which would have maintained a speed within 1 per cent., or less, under certain conditions, *i.e.*, when the change of load was not a very large percentage of the whole. In the test of the Knowles

Mr. Richardson. governor, for instance, in which Mr. Druitt Halpin had used the Moscrop recorder, there had been a sudden variation of 150 HP. with a variation of $\frac{3}{4}$ per cent., but the total power was not stated. If it were a variation from 150 HP. to no load, in an engine the maximum power of which was 150 HP., the result was remarkably good; but if of an engine with a total of 600 HP., the result was good, but not extraordinary. He had frequently seen loads of 100 HP. suddenly put on and off a 400-HP. engine fitted with the gear shown in Fig. 19, without producing any perceptible variation of speed, and the shaft governor shown in Fig. 15, or the link gear in Fig. 17, would admit of such a percentage of load being put on or taken off, without a variation in the speed of more than 1 per cent. In the tests he had made the engines were in all cases driven with their maximum load at a definite speed, and with full admission, and no governor control at all, *i.e.*, with the balls in their lowest position; then, the variation was that shown where all the load was taken off, and the governor alone controlled. With regard to Mr. Raworth's remarks, comparative tests of English and American governors were given in Table I, p. 215. He had no doubt as to the accuracy of the results, but did not give the name of the American governor, because the tests were not carried out under the superintendence of the makers. Questions had been asked as to the meaning of *Fig. 16*. He had said in the Paper: "The diagram, *Fig. 16*, shows graphically the relation between the calculated, experimental, and theoretical pressures of a spring resisting a certain centrifugal force." Assuming the total height of the *Fig.* to be represented by 100, the position of the various inclined lines all bore a relation to this number. Now, if a known weight revolved at a given radius and at a definite speed, it would have a certain centrifugal force, and when removed further from the centre it would have a proportionately greater centrifugal force, which might also be obtained by calculation. The theoretical line was obtained from such results, and was represented by the dot-and-dash line in the diagram. The different heights of the two ends of this line showed the different tensions of the spring required to balance the centrifugal force at the inner and outer positions of the revolving weight, provided that such weight were quite free to move outward, except in so far as it was controlled by the spring. But when the weight was of the form shown in Fig. 15, in which one end was secured by a pin, it no longer acted as it would if free to move in its entirety, and experiment showed that if a spring corresponding to the different distances of weight were used, the governor hunted badly,

Mr. Richardson.

and by experiment a spring was found which just allowed a variation of, say, 3 per cent. in speed. The spring so found by experiment was shown by the plain dotted lines.

The results of three experiments were given in *Fig. 16*, one for a governor controlling an engine at 300, one at 250 and one at 200 revolutions per minute, and in all these cases a difference was found of half the smaller pressure of the spring, the higher pressure remaining constant. Of course with the balls thus balanced at all points they would stand indifferently at all points, but by adding double the percentage of variation in speed allowed to the greatest pressure of the spring, the line representing it took the position shown in the diagram crossing the theoretical line at the same point in all cases. This line represented the pressure of the spring as found by experiment. The black line was one nearly corresponding to it, and was called the calculated line, because in practice with such a disposition of weights and springs as shown in Fig. 15, the foregoing calculation gave at once the two pressures of spring required to secure governing within a percentage of 3 per cent. He did not, as one or two members appeared to think, claim to have been the first to introduce the shaft governor, but he believed that that shown in Fig. 12, which was first exhibited in 1869, was the first one used in England. Messrs. Hartnell and Guthrie had patented one some months before, though he believed that his was the first introduced to the public, and that for several years from that date, viz., 1869, it and the Hartnell governor were the only shaft governors used in England. It would be seen on reference to Table I, that at all pressures between 50 lbs. and 100 lbs. per square inch, first, the possible power developed was less with the American than with the Robey governor; and secondly, while the variation in speed with the shaft-governor was between 2·8 and 3·8 per cent. only, the variation was between 9·5 and 15·2 per cent. with the American governor under the same conditions as to engine and load. The amount of momentary fluctuation was in most cases greater with the American type, though at its lowest duty it was nil, while at 100 lbs. per square inch pressure it was 25 per cent., whereas with the shaft-governor it was less than 9 per cent. fluctuation. There was, however, one slight advantage possessed by the American governor. Although it varied through a wider range, it came to rest as might be expected somewhat more quickly. The 1 per cent. variation stated by some American makers for their governors was unattainable if the variation in load was so extreme as in the tests he had applied,

Mr. Richardson. though such accuracy might be obtained easily by any good governor under more favourable conditions. He agreed that the compounding of dynamos was now so well accomplished that electrical regulation for varying speeds was not now so much needed for incandescent lighting in parallel, but for series lighting it was not only useful but was much used; and he was also surprised that it had not been more used for the purpose of meeting the sudden and great variations in load of electrical tramways. There was one incidental advantage in connection with electrical regulation, viz., that while the speed varied the cut-off remained practically constant and thus the engine was enabled always to work with the best distribution of steam. It was well known that there was one best point of distribution in compound or triple-expansion engines, and this distribution of steam could be maintained when the power of the engine was varied by varying its speed. With regard to the Willans electrical governor this was referred to on p. 212 of the Paper, and as he had been afforded an opportunity of taking part in the discussion on that Paper,[1] there was no need to repeat his views now. It should be remembered, however, that the Willans governor was fitted with an hydraulic relay of very ingenious construction, but with unnecessary complications.

The criticism offered by Mr. Rigg was interesting; the illustration of the Watt governor shown was not a working drawing, but merely a diagram illustrating the type. He quite agreed that it was a "non-sensitive governor working through an extremely small space," and that the governor shown in Fig. 17 was by far the best. With regard to Fig. 14, the present form was only about two years old, and was shown as a modification of Fig. 12, the principle of which was the same. His experience with shaft-governors only went back some twenty-five years, and he believed those of Mr. Hartnell, and that shown in Fig. 12, were among the first and were the only ones used for some years. With regard to the wedge motion adjustment, this was an independent invention so far as he was concerned, and he still thought it was then for the first time used in connection with a governor, though he had learned afterwards, what perhaps he ought to have known before, that it had been invented many years earlier and used as an adjustable hand-reversing gear. With regard to the position of the centres in Fig. 15, in order to place them where Mr. Rigg had suggested would require, as he rightly said, that

[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 202.

Mr. Richardson.

the diameter of disk should be considerably enlarged, and the position shown gave the advantage of more compact form, and the governing power was extremely good. He fully endorsed Mr. Rigg's remarks, that the best thing, "in order to get a governor to do its work well, was to give it nothing to do." This had been carried out with the governor and expansion gear shown in the model, and in Figs. 19 and 20. The power required to do all the adjustment from zero to $\frac{7}{8}$ cut-off was practically nil, so that the governor might be made extremely sensitive, as there was absolutely no strain upon it. With such a governor and valve-gear there was no difficulty in governing well to within less than 1 per cent., even without the supplementary governor alluded to by Mr. Druitt Halpin.

With regard to the best movement for throttle-valves he had in a few cases used one adjusted by turning upon an axis instead of sliding. It required very little power to move it, but it needed extreme accuracy to obtain a sufficiently good fit to prevent leakage, and still remain sufficiently free to prevent sticking. Further it had the disadvantage of requiring a weight or spring to pull it open so as to take up any backlash, a disadvantage which did not rule with the valve shown in Fig. 10. The disadvantage of a vertical sliding movement was less than appeared at first sight; the total vertical movement in this valve was about $\frac{1}{2}$ inch, and it took this every time the engine was stopped or started, while the amount of movement for adjustment seldom exceeded $\frac{1}{16}$ inch. It had been asked by Mr. Phillips how a governor could be made to increase the power of an engine, and at the same time economize steam. While the statement might seem paradoxical, the answer was quite easy. Governors had to deal with varying loads; an engine without a governor must be set to either the smallest load, the greatest, or what is more probable, the average. In the latter case, when a greater load was applied, the speed and therefore the power of the engine would fall; and when the load was reduced, the steam would be admitted at a less economical cut-off, and wasted in running the engine too fast; while, with a good governor, controlling either the throttle-valve or the expansion-gear, neither of these evils would take place, and an engine so fitted would be both more powerful and more economical. It had been asked whether he had seen the Thury automatic regulator used in Switzerland. He had not, but his attention had been called to an illustration of it. It was apparently a very good governor, and he had no doubt would work well. It would be seen that it had

Mr. Richardson. many features in common with the electric regulator shown in Fig. 28.

In reply to Dr. Hopkinson, it was hardly correct to refer to *Fig. 16* as showing a discrepancy between the recognised laws of centrifugal force and practical application. He had the greatest reverence for the ascertained laws of motion, but it would be admitted that there was a difference between the movement, and therefore, control, of a body free to move in all its parts, and the same body controlled and fixed by a pin at one point. The allowance that should be made for this, and other forces which came into play, would no doubt be easily calculated, but such a calculation would be tedious and liable to error. All that was given in the Table prepared by Mr. Wansbrough was a simple and very convenient graphical method of arriving at the same result. He desired to thank Dr. Hopkinson for pointing out how, in governing by electricity, it was possible to compensate for the loss of pressure over the resistance of the conductors in a simple way, and did not doubt that the way suggested would be very effective.

He agreed that the Proell governor was first designed in 1871. As he had stated, however, it was introduced into England through his firm in 1884, and he was given to understand then that it was a recent invention. He found on reference that the English patent was taken out in 1881. With regard to the question of stability, he meant by a stable governor, one which, when revolving at a definite speed, resisted any extraneous force to cause it to change its position, and which when forced from its position immediately returned to it. This quality was possessed in an eminent degree in the spring governors shown in Figs. 12, 15, and 19, and his experience with more than one hundred Proell governors had convinced him that this was a quality which that governor lacked. The fact that Dr. Proell's licensees no longer used the governor shown, but now used a powerful spring in connection with it, entirely confirmed his statement as to the superiority of the spring over weight- or gravity-governors. The dashpot (or air-brake, as Mr. Kühne had called it) was applied to the Proell governor to prevent the dancing of the balls, and had been introduced because such a governor needed it. Being merely an air-cushion, it did not answer its purpose perfectly, though it diminished the movement. Mr. Kühne's statement that the influence of gravity was not eliminated in any governor with rising and falling balls was correct, and it was for this reason that a governor like those

shown in Figs. 5 and 12 was preferred where the balls flew out in practically a straight line. The governor shown in Fig. 17 was also designed on the same principle, and when used in a horizontal position the sleeve was fixed and the centre spindle moved. He thought that experience in making or working engines showed that throttle-valves reduced their maximum power. There were practical limits to the relative size of a throttle-valve to an engine, and any such valve interfered with the free passage of steam, and to that extent reduced the power of the engine. If an experiment were tried with a throttle-valve of any size, it would be seen at once that there was a material difference between the maximum loads an engine could carry with and without such a valve.

Mr. Richardson.

With regard to the indicator-diagrams, they were given merely to illustrate the action and range of the valve-gear, and contained all the lines necessary for that purpose. The statement that there were fewer parts in the Proell gear was not correct, and the illustration given was not altogether a fair one. In counting the parts of the Robey trip-gear, Mr. Kühne enumerated every joint between the valve and the governor, whereas in the working paper model shown of the Proell gear the governor and its connections as used in actual practice were entirely omitted. His further statement that in the Proell gear there was no possibility of friction coming between the governor and the gear was also doubtful. When the bell-crank or tripper which depressed the valve lever was doing its work, one of its arms was depressing the valve lever and the other arm rested on the moving collar connected with the governor, and a very perceptible pressure was put on the governor at that time, tending to produce the dancing or oscillation objected to. On the other hand, in the Robey gear this lever or tripper was connected entirely with the eccentric rod, and did not touch the governor, which was thus quite free from the mechanical part of the valve gear, and had no work beyond a fine adjustment of the centre of the lifting lever H, Fig. 20, Plate 1.

The subject of the Paper had naturally and rightly been looked at by Professor Unwin from a theoretical and scientific standpoint, and such standpoint was a most important one. He had, however, in the introduction to the Paper stated clearly that as so much attention had been already given to the subject of governors from a theoretical point of view, he would confine himself entirely to the results of practice. It would probably be admitted that though some conclusions might have been

Mr. Richardson. arrived at, and stated without all the reasons being given for them, yet, that a set of conclusions arrived at upon a particular subject, through observations of the practical working of several thousands of examples during a period of over a quarter of a century, might at least rank as of equal value with those formed from the observations of a limited number of laboratory experiments and calculations. He stated this without in the least wishing to depreciate the value of such experiments. With regard to the dashpot referred to by Professor Unwin, that used in connection with a governor controlling expansion-gear was generally employed to prevent small and rapid fluctuations in the position of the governor while permitting a wide range of movement. This object could not be attained with an elastic medium filling the dashpot cylinder, because air offered but a slight resistance to very small and frequent movements, though it was a good regulating medium for large and slow movements. The contrary was the case when a piston, with a small hole in it, worked in a cylinder filled with an incompressible fluid. The small oscillations were prevented because the fluid could not pass rapidly from one side to the other of the piston, but the latter was perfectly free to take up its place in any part of the cylinder, the rate at which it could be moved being determined by the pressure upon it and the size of the regulating hole in the piston.

With regard to Fig. 4, though designed by himself, as stated twenty years ago, it was perhaps in culpable ignorance of either the Farcot governor or the book in which it was referred to. That a similar design had been made previously was by no means unlikely. Many of these governors were at work and gave good results in controlling throttle-valves, Fig. 2, but were of no use for expansion-gears where considerable power was required to move the working parts.

It had been rightly said "that the Paper as a whole was a plea for the use of automatic-expansion governing," but he did not go so far as to say that "there were no terms too bad to be used in regard to the want of economy in proceeding in any other way." It was, on the contrary, stated in the Paper that for many purposes such a valve as Fig. 10, *i.e.*, a throttle-valve, was all that was required. The advantage, however, of automatic expansion-gear was so well recognised that the method of throttle-valve governing was defended principally by those engineers who did not apply automatic gear. He agreed "that trip-valve gear could be controlled by a governor so as to

maintain considerable accuracy in speed," but entirely differed from thinking "that in other classes of valve-gear the real solution of the problem lay in the relay." When such a relay as Professor Unwin had indicated had been used for any considerable length of time, and found to avoid hunting, his opinion might be modified, but not until then. On this subject it would be recalled that the Allan link-expansion gear, the Hartnell gear, and others of that class, as well as that shown in Fig. 17, did now govern "so as to produce very considerable accuracy of speed" without any relay being needed, and such relays were, in his opinion, quite unnecessary conditions to a good governor gear. The principal objection to slide-valve gears was not that they did not govern well, but that in large engines the movement of the valve absorbed too much power and necessitated a large and expensive governor. Relays, especially those controlled by electricity, doubtless, were useful in moving turbine sluices, but were not needed for governing engines. These observations applied also to a great deal which had been said by Mr. J. Swinburne, with whose other remarks he was in accord. Replying to Mr. Wingfield respecting the movement of the balls in Fig. 5, the reason why it was an advantage for the balls to diverge in a straight line, or, as it might be better described, "revolve in one plane," was that in so doing gravity was eliminated, as there was no weight lifted, and such a governor would work as well horizontally as vertically. The governor, Fig. 5, was an experimental form only of that of similar design shown in Fig. 12; two or three hundred examples had been made, and were in all cases used horizontally. Mr. Richardson.

He would like to correct an impression which seemed to have been conveyed, viz., with regard to the lifting- and forcing-power of the spring-governor, Fig. 17. Naturally the power of the governor did not correspond to the pressure of the spring only. When the balls were closed the spring was exerting a force of 216 lbs., when wide open the spring was compressed until it exerted a force of 416 lbs. While this was so, yet when a certain speed was attained the centrifugal force generated by the revolving balls just balanced the spring pressure at the lowest point, and as the speed increased of course balanced it at every point; but at slightly different speeds, the centrifugal forces were balanced only at one particular point of its travel, when this corresponded to a certain speed and no other, and a very considerable pressure was needed to force the sleeve out of this position for any distance, and it tended instantly to return to it. That governor

Mr. Richardson. therefore had the greatest lifting- and forcing-power which, when revolving at a speed corresponding to its lowest position, would require the greatest force to make it take up the highest position at the same speed, and, conversely, when revolving at a speed corresponding to its highest position, would require the greatest force to make it take up the lowest position. In some governors this lifting- and forcing-power was very small, but in such as shown in Figs. 17 and 19 it was very great; these being forms of governor which combined delicacy and quickness of action with great power.

Correspondence.

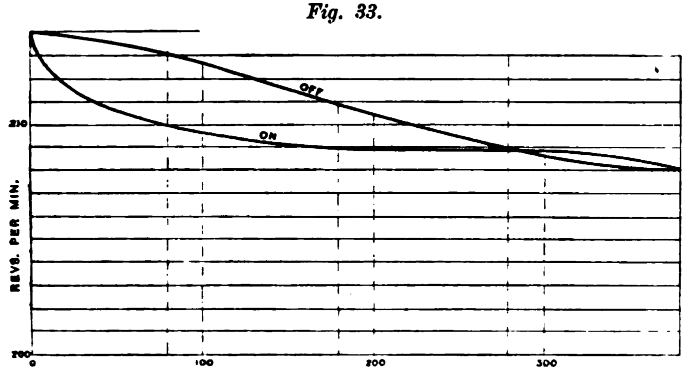
Dr. Anderson. Dr. W. ANDERSON desired to contribute a statement as to some successful governors he had met with in connection with the prize competitions of the Royal Agricultural Society of England. At the trials of thrashing-machines at Cardiff[1] in 1872, an eight-horse portable engine, by Aveling and Porter, was coupled direct to a rotary dynamometer through which the competing machines were driven. It was regulated by a high speed Porter governor actuating a butterfly throttle-valve which differed only from ordinary valves in the spindle passing through the valve about $\frac{1}{16}$ inch to one side of the centre, and the valve was so placed that the steam issuing from the boiler and acting on the unequal wing of the valve, always tended to open it. By this arrangement the proclivity of throttle-valves to stick, when quite closed, was so completely overcome that the engine did not vary 2 revolutions in 120 when the load was suddenly removed. At Newcastle[2] in 1887 a variety of governor gears fitted to the portable engines under trial were exhibited. The best was unquestionably the arrangement adopted by Messrs. Davey, Paxman and Co., both to their simple and compound engines. The valve gear consisted of a main and cut-off slide-valve, the latter deriving its motion from a link controlled by a Paxman high-speed governor. Each end of the link was connected to an eccentric, one giving a late cut-off and the other closing the admission ports altogether. The cut-off plate had twin parts with the object of reducing its travel. The governor controlled the speed absolutely, and did not permit the least hunting. A Farcot cut-off arrangement, applied to two of the engines, though efficient in regulating the speed on the average, did not prevent hunting. There were other varieties of governor

those eal[illegible] the Royal Agricultural Society of England, vol. viii. 1872, p. 409.
“ that trip-vaiii. 1887, p. 667.

gears at the trials, but were not so successful, mainly owing to imperfections of workmanship and adjustment. It was evident that if a governor gear had to control an engine from full power to no load, the valve or valves must be able to close almost completely and yet must not stick in any way, and such a state of things could only be attained, in most cases, by careful attention to details of design, to perfect fitting and to adjustment. Dr. Anderson.

Mr. Geo. R. Bale observed that in Table III, p. 219, for a given increase of the load there resulted a certain decrease in the speed of the engine, whilst for an equal decrease in the load there obtained a different corresponding increase in the speed; thus the Table indicated that by increasing the load from 80 amperes to 280 amperes, the revolutions fell from 210 to 209 per minute, or a difference of one revolution per minute; whereas for an equal Mr. Bale.

Fig. 33.



decrease in the load, from 280 to 80 amperes, the corresponding increase of speed was from 209 to 213, being a difference of four revolutions per minute. The results were shown graphically in *Fig. 33*, and it would be interesting to know whether this condition of things was usually to be found, or was due to faulty action of the governor, consequent upon its sticking or some other cause.

Mr. Jeremiah Head stated that the Author had disclaimed any intention of dealing with the theory of the action of steam-engine governors. On pp. 213, 214 and 218, however, he seemed to some extent to trace their development, theoretically as well as practically, from the Watt type (Fig. 1, Plate 3), which he said was in almost universal use until a few years ago, to the governor (Fig. 5) designed by himself in 1869, wherein he had introduced a spring to resist the centrifugal force of the revolving weights; and six Mr. Head.

Mr. Head. years later he had designed the weighted cross-armed governor (Fig. 4).

Attention had already been called to certain omissions, if the Paper were to be regarded as a historical record from the time of Watt. Concurring in this view, and being convinced that the Author was not aware of all that had been done before he designed the governors (Figs. 4 and 5), he ventured to refer to a few facts bearing on the subject within his own personal experience. At the great Exhibition of 1851, an exhibitor from Vienna showed a form of governor or conical pendulum in which the balls were so guided as to rise and fall in parabolic curves. This had the effect of producing almost absolute isochronism, that was to say, any variation whatever in the speed of the engine made the balls travel to the full extent of their range, unless and until the action on the regulating valve thereby occasioned was sufficient to restore the normal speed. Such a governor seemed to be theoretically perfect. A little later, an Englishman named Garnet had designed several forms of the parabolic governor, one of which was the cross-armed approximation to which reference would be again made. In 1856, whilst still a pupil of the late Robert Stephenson, at Newcastle, he had been entrusted with the design of a pair of compound condensing-engines for a woollen mill at Darlington, wherein uniformity of speed was insisted on. He had received permission to adopt the parabolic governor, but when the engines had been tried, considerable difficulty had arisen from "chasing." A cataract had been added to the governor to prevent the accumulation of momentum in the balls, and it had been found that this device, if made of ample size and containing air only, removed the difficulty. Several air-controlled parabolic governors had been subsequently made at Messrs. Stephenson's factory, and some were probably working to this day. They were applied both to ordinary throttle-valves, and to variable expansion-gears. The cross-armed governor, the balls of which were so hung on opposite sides of the vertical spindle as to rise and fall in circular arcs nearly coinciding with portions of a parabolic curve, was a variation designed at the same time and place independently, and in ignorance of the existence of Mr. Garnet's invention. They had also been at first controlled by air-cataracts, and had proved sufficiently perfect for all ordinary purposes. The substitution of a spring for a cataract had, so far as he knew, been first suggested in 1857 by the late Mr. George Crowe, chief foreman at Messrs. Stephenson's works. By making this spring of sufficient strength, and driving the governor at a higher speed, the size and cost of

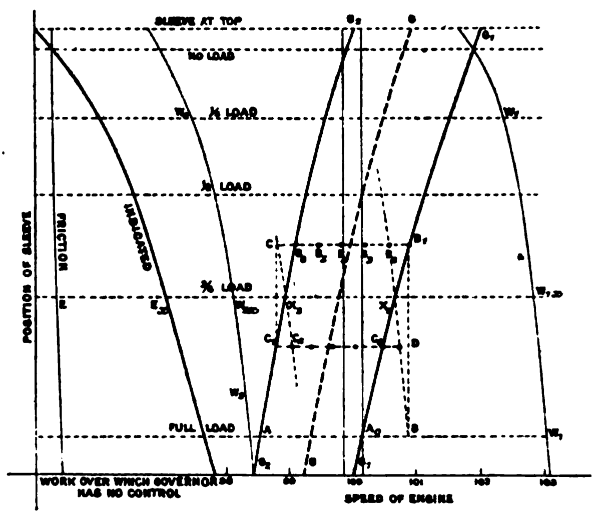
the apparatus was greatly diminished, and in this form it gradually superseded the more perfect, but larger and more costly parabolic governor. As shown by the Author, other and more modern designs had gradually superseded the above historical types, which had been doing good work nearly forty years ago and for long after. The improvements which had produced this result seemed to be in the direction of further increasing the force, whether it were a weight, or a spring, whereby the balls were kept closed; and by diminishing the mass of the balls, and driving them at still higher speeds. By these means a very small, simple, and yet highly efficient governor had been gradually evolved. Mr. Head.

Mr. F. W. E. Jones referred in terms of praise to the electrical method of regulation, as far as he had had experience of it, at Leamington Spa. He had under his control there two compound condensing-engines, each capable of developing 250 HP., which were fitted with electrical governors practically the same in arrangement as shown on Fig. 27, Plate 3. Their solenoids were excited by either of a pair of dynamos driven by each engine. The conditions of working made it essential that the speed of the engines should be capable of variation, in steps equivalent to 1 volt at a time, and in accordance with the variations of load occurring while the engines were at work. This was effected by an adjustable resistance placed on the instrument table and under the control of the attendant. The regulation was perfect in every respect, and any desired increase or decrease of electromotive force was immediately obtainable either in steps of 1 volt or more at a time, according to the plates inserted or taken out of the resistance. It seemed to him that it would be equally simple to arrange for the addition or otherwise of any fraction of a volt if requisite, or, by a modification, for a constant speed irrespective of the load. He noticed that no case had come to the knowledge of the Author in which the action of a safety appliance or a mechanical governor had been needed. In this station, however, through a fault which developed in the winding of one of the solenoids, the mechanical governors had been in one instance called upon to prevent the engine running away; with solenoids as the Author suggested upon a vulcanite, instead of upon a brass bobbin, this failure would not have occurred. In his opinion where absolute uniformity of speed under varying loads was necessary, an electrically-controlled engine would be found more satisfactory than one governed by any centrifugal arrangement. Mr. Jones.

Mr. A. Sharp observed that in discussing the regulation of the speed of an engine there were three elements which should be Mr. Sharp.

Mr. Sharp. considered separately, viz.:—(1) the governor; (2) the work which could be done by the steam in the cylinders at any instant, on its further passage through the engine to the exhaust-pipe, and (3) the inertia of the reciprocating and rotating parts; or briefly, the fly-wheel. With regard to the second, the steam having already passed the admission or cut-off valve, the governor could have no influence on it, and if the whole external load were suddenly thrown off, the work done by the steam in the cylinders was expended in increasing the speed of the engine. Briefly, that element might be referred to as the engine. The effects of these three elements on the speed could be conveniently

Fig. 34.



represented on one diagram. The effects of the first two of these elements had been represented by Professor Dwelshauvers-Dery [1] in a convenient diagram, on which the third might also be shown as on *Fig. 34*, in which $G_1\ G_1$ represented the relation between the position of the sleeve of the governor and the speed of the engine when the sleeve was rising, and $G_2\ G_2$ when falling. The left-hand portion of the diagram represented the work done by the steam, over which the governor had no control. In a single-cylinder expansive-engine that would be at least equal to the work expended during expansion; in a single-cylinder engine governed by a

[1] Minutes of Proceedings Inst. C.E., vols. xciv. civ. cx.

throttle-valve it might be equal to the total work of a stroke; while in a triple-expansion engine it might be equal to the work done per stroke in the high-pressure cylinder, in addition to twice the work per stroke in the intermediate cylinder, and three times the work per stroke in the low-pressure cylinder. Probably the only governor which would actually prevent racing, in a marine engine, would be an anticipatory governor, which not only regulated the admission of steam, but also throttled the exhaust from each cylinder. If, when the position of the sleeve and the speed of the engine were represented by the point X_1, the whole load were thrown off the engine, the work $E\,E_x$ would be expended in increasing the speed to the value represented by W_{1x}. The more powerful the fly-wheel the smaller would be the increase of speed $X_1\,W_{1x}$. If the fly-wheel were so powerful that the increase of speed was small, the intercept $X_1\,W_{1x}$ would be proportional to $E\,E_x$. Similarly, if, when the sleeve position and the engine speed were represented by the point X_2, the maximum load be thrown on, the speed would fall to the value represented by W_{2x}. If the necessary data for drawing the curves $G_1\,G_1$, $G_2\,G_2$, $W_1\,W_1$, and $W_2\,W_2$ were available, the variation of speed due to increase or diminution of the load could be clearly shown on the diagram. If, for example, the engine were running steadily at full load, and one-fourth of the load were suddenly thrown off, the points A_0 and X_1 on $G_1\,G_1$, corresponding to full load and three-quarter load respectively, the increase of speed of the engine would be the difference between $A_0\,W_1$ and $X_1\,W_{1x}$. If there be drawn through X_1 a line similar to the fly-wheel line $W_1\,W_1$, cutting the line of full load at B, and from B be drawn a vertical line $B\,B_1$ cutting $G_1\,G_1$ at B_1, then the speed of the engine would increase an amount shown by A_0 B, and the sleeve of the governor would rise to B_1. But this position of the sleeve would correspond to a smaller load than that actually on the engine, and, therefore, the speed would fall; the speeds at the ends of the second, third, and fourth strokes being represented by B_2, B_3 and B_4. If B_6 lay on $G_2\,G_2$, and the speed fell still further, the governor sleeve would fall and more steam would be admitted. A curve $C\,X_2\,C_2$ through X_2, similar to $W_2\,W_2$, being drawn, cutting the horizontal through B_0 at C, and through C a vertical line $C\,C_1$ cutting $G_2\,G_2$ at C_1, at the next stroke the speed would fall an amount B_6 C, and the sleeve to C_1. This position of the sleeve would correspond to a higher load than that on the engine, the speed would consequently increase, and at the end of successive strokes be represented by C_2, C_3, C_4. If C_6 lay on the line $G_1\,G_1$, the same

Mr. Sharp.

Mr. Sharp. cycle of operations would be again performed. From this diagram, if the lines $G_1 G_1$ and $W_1 W_1$ were nearly straight, some important conclusions might be drawn. (1) If the fly-wheel line $W_1 W_1$ and the governor-line $G_1 G_1$ sloped in different directions, then on a change of load the governor-sleeve would oscillate for some time before taking up a steady position. (2) If the fly-wheel line $W_1 W_1$ were less steep than the governor-line $G_1 G_1$, the governor would hunt persistently, and the sleeve would travel suddenly between the top and bottom positions. This defect ought not to be attributed solely to the over-sensitiveness of the governor, but rather to the insufficient proportions of the fly-wheel. (3) If the fly-wheel line $W_1 W_1$ sloped in the same direction as the governor line $G_1 G_1$, the engine would quickly approach a position of steady running, and would not over-shoot it. (4) If the fly-wheel line $W_1 W_1$ were vertical, the engine would settle down most quickly after a change of load.

As regards the practical determination of the data for the *Fig.*, the line G G of the governor, regarded as a frictionless tachometer, could be calculated from the arrangement and weights of the governor parts. The lines $G_1 G_1$ and $G_2 G_2$ could only be satisfactorily determined experimentally, and since they included the frictional resistances of pin-joints, bearings and stuffing-boxes, they might vary considerably from time to time. The accurate estimation of the work over which the governor could have no control would also be difficult. The effect of the fly-wheel, on the other hand, would be unvarying, and its determination should present no difficulties.

The influence of a Knowles supplementary governor might be represented on the *Fig.* by two vertical lines situated close together. Immediately after a change of load on the engine, the principal governor would act in the manner described above; but if the speed of the engine be the least or greatest, X_2 or X_1, consistent with the new sleeve position, the supplementary governor would press one or other of the friction-disks on its spindle against a friction-wheel, which, by suitable mechanism, turned a nut and altered the length of one of the links from the principal governor-sleeve to the throttle-valve, thus admitting more or less steam to the engine, until its speed was very near the mean. The frictional resistance of this supplementary gear being very small, the variation of speed might be made very small. Thus, while the instantaneous speed-variations, due to sudden alteration of load, lay within the lines $W_1 W_1$ and $W_2 W_2$, the permanent variations would lie within much narrower limits.

Professor R. H. THURSTON had found the Author's account of the new forms of electrical steam-engine governor exceedingly instructive. He was not aware that anything of importance had been accomplished in this direction in the United States; but the perfection attained there by the shaft-governor—originating he thought in England, with Messrs. Hartnell and Guthrie—had reached such a point that where uniformity of speed was the purpose of the regulation, there was no occasion to look beyond present practice to meet every demand. Where it was required to adjust a variable speed to a variable load in a definite manner, he could imagine that these electrical governors or modifications of them would meet that demand better than could any adaptation of the shaft-governor, though some American inventors, notably Mr. F. H. Ball, had succeeded in producing a governor of the latter class which could be made to give increasing speeds with increasing loads and the reverse. In such cases as would be met with where a decreasing current with constant potential was needed for lighting purposes, these new devices, in which the current itself was utilized for effecting regulation, seemed likely to find applications in a beautiful way. Prof. Thurston.

It might interest members to learn what had been done in the United States towards the improvement of governors. With low-speed engines, and especially those of large size, making less than 200 revolutions a minute or thereabout, the Corliss system of valve-gear and regulation was almost exclusively employed, and a very large number of engines of that class were used in electric-light and power stations. The essential idea of that system, so far as related to regulation, had originated, he thought, in 1834, with Mr. Zachariah Allen, who, at that date, designed the combination of the governor and a variable expansion-gear, in such manner as to regulate the point of cut-off by a governor. This idea, original probably also with Mr. Corliss, was made a prominent feature of his engines; and the peculiar ease of detachment of his valve, and its consequent slight effect upon the governor itself, afforded excellent and wonderful regulation for his engines at that date. A limit of 2 per cent. variation of speed, between full load and friction-load, should be easily attained, and even closer regulation had been stated to have been obtained by some builders. With the introduction, however, of the shaft-governor on high-speed engines, and with the application of such engines to the exacting duty of supplying power for electrical transmission, there arose an unexampled demand for, and soon a no less unexampled perfection of, the regulation of the machine.

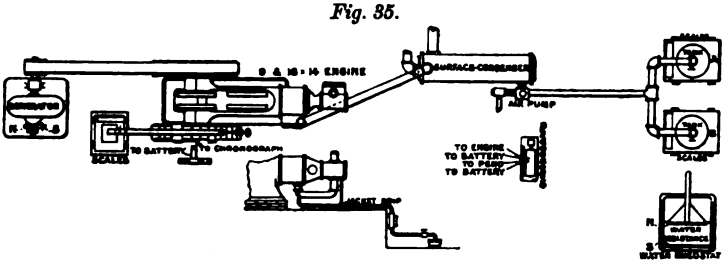
Prof. Thurston. A limit of 1 per cent. regulation was now considered not at all unreasonable, and still closer governing was reported. As long ago as 1883, he had had occasion to have tests made of the power and regulation of the "straight-line engine," of Professor Sweet, and had then found one of those machines working within the latter limit. The machine was rated at 25 I.HP. at 230 revolutions, and he had been surprised to find that it was actually working at a speed of 230 revolutions per minute loaded, and 231 revolutions when the engine was entirely free from external load,[1] and was merely overcoming its own friction of about 5 per cent. Another firm had made a public tender of a guarantee that its engines should not vary 1 per cent. from the regular speed, between full load and no load, and that the purchaser, in the event of its failing to fulfil this test, should have the engine on payment of one dollar. He had been informed that many engines had been sold under this guarantee, and that none had yet been forfeited. One secret of success lay in the fact that all such builders of first-class engines were establishing "testing departments," in which each engine was mounted on a foundation arranged for the purpose, and was tested for power and speed. As exhibiting what might be accomplished with these high-speed engines fitted with shaft-governors by good design and construction and skilful handling, he quoted the following data and results obtained in a test recently reported on by Professor Carpenter and himself, in which the chronograph was employed for accurate determination of the speed variations. The chronograph had been built to his order, for Sibley College, Cornell University, and especially for engine-testing, by the Société Génévoise. It had three speeds, and gave thorough satisfaction in its performance. The current was broken by the engine at each revolution, making its record on the chronograph cylinder. The pendulum was standardized, its error being found to be one second in 360, for which due allowance was made. Its apparent record was in seconds. The chronograph-drum rotated at a speed so arranged as to give about 1 inch of longitudinal movement of the pencil per second. The load was a 75-HP. dynamo, of which the current was absorbed by a water-rheostat. The usual methods were adopted of measuring current and voltage, and loads could thus be thrown on and off or varied as suddenly as desired. The arrangement of apparatus was shown in the plan, *Fig. 35*. Tests, both of economy and of regulation, had been

[1] Transactions, American Society of Mechanical Engineers, vol. viii. 1886–87, p. 86.

Prof. Thurston.

made by Professor Carpenter. A simple engine had also been compared with a compound, both engines being controlled by a form of shaft-governor, with "inertia detachment," as built by Mr. McEwen, with the following results. With steam at 80 lbs. per square inch by gauge, and load 70 I.HP., the steam-consumption of the simple engine of 12 inches diameter and 14 inches stroke, was 30·7 lbs. per I.HP. per hour, coal 3·4 lbs. at an evaporation of 9 to 1. The best work had been at one-third cut-off, and the economy varied little between 40 I.HP. and 90 I.HP. The clearance was large, 8·75 per cent., and probably to the disadvantage of the engine in respect to efficiency. The compound engine had cylinders 9 inches and 16 inches in diameter, and 14 inches stroke. Jackets were employed on heads and sides. With jackets at work on both cylinders, the steam-consumption, non-condensing, was 23·13 lbs., with the high-pressure engine only jacketed 23·91 lbs., with the jackets shut off both cylinders, the water-consumption was

Fig. 35.

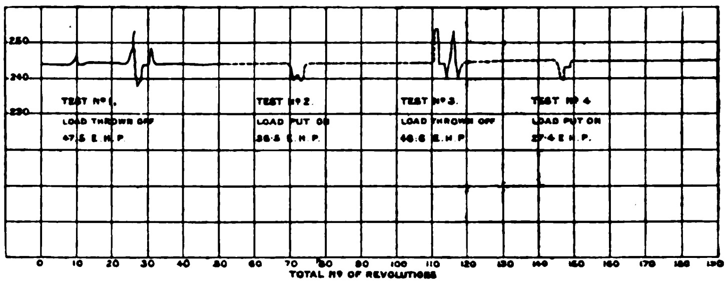


PLAN OF APPARATUS FOR HIGH-SPEED ENGINE TEST.

23·81 lbs. per I.HP. per hour. Thus the gain by the jackets was 2·85 per cent., giving, as computed at the time, 10 per cent. return on $382, or, in other words, a handsome interest on the cost of jackets, even at this low figure for saving. When condensing, the engine reduced its steam-consumption to about 18·5 lbs., but the vacuum obtainable at the time was unsatisfactory, in consequence of the inadequate power of the air-pump then available, and the figure had little value. In these trials, the jacket gave considerable gain at high ratios of expansion and little at low ratios. At the rated load of the machine, 100 I.HP., the gain was 5 per cent. The influence of change of load in reduction of economy, varying either way from the rated power, was less, proportionally, with the compound than with the simple engine. During these trials, the loads were occasionally thrown off instantaneously, and thrown on as suddenly, by breaking and again making contact at the circuit breaker. At such instants, the tachometer, which was

Prof Thurston. attached for the purpose of exhibiting such variations, would jump in the case of the simple engine, for an instant, from 244 revolutions to 250 revolutions per minute, and in a second or two settle back at 244 revolutions as seen in *Fig. 36.* The total time of fluctuation was about 1·6 second, but the total average increase of speed for the minute was 0·3 revolution. Throwing on the load again, the reverse action would occur, the jump taking place from 244 revolutions to 243·8 revolutions and the mean variation of rate being, for the minute, as before, 0·3 revolution.

Fig. 36.



VARIATION OF SPEED REDUCED FROM CHRONOGRAPH.

The gradual changes of load were produced by the use of a Prony brake.

Mr. Richardson. Mr. RICHARDSON, in reply to the Correspondence, considered, with reference to Dr. Anderson's remarks as to a portable engine fitted with a wing throttle-valve used at the thrashing-machine trials at Cardiff in 1872, and which only showed an acceleration of two revolutions when the load was suddenly thrown off, that while this was doubtless a good result it proved nothing for or against the views he had put forward. As no particulars had been given of the load, and if used merely for driving a thrashing-machine an 8 HP. engine would only be working up to about half its maximum power or less, and from an examination of the indicating-diagrams from a number of other engines tried at the same time, it was evident that they were working at less than half their power, the cut-off varying between about $\frac{1}{8}$ and $\frac{1}{3}$. There were many valves and governors which, when working within a small range, would maintain a nearly uniform speed, but which would admit of very wide variations between the maximum load of the engine and no load. The only critical test as to the value of governor gear was to apply a load to the engine until the governor balls dropped to their lowest position, and then to suddenly remove it. Had such a test

been applied to any wing throttle-valve it would have shown widely different results. With regard to Table II, page 218, the difference in the variation of speed in an increasing and decreasing load did generally follow as indicated, due doubtless to friction in the governor, but as the variation in the case noted was only about 2 per cent., *i.e.*, 209 to 214, the action of the governor could not rightly be called faulty. The total variation from no load to the maximum load, *i.e.*, from 0 to 380 amperes, was only five revolutions, or less than 2½ per cent. While this was less perfect governing than could be obtained with the trip-gear shown in Fig. 19, Plate 3, yet it would compare favourably with any form of slide-valve gear tried under equally severe conditions. The remarks of other correspondents had considerable interest, and he was gratified that so much valuable information had been brought forward.

Mr. Richardson.

---

12 February, 1895.

Sir BENJAMIN BAKER, K.C.M.G., Vice-President, in the Chair.

The discussion upon the Paper on "The Mechanical and Electrical Regulation of Steam-Engines" occupied the evening.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2772.*)

"The Construction and Equipment of the Tilbury Docks."

By Jesse French Scott, Assoc. M. Inst. C.E.

The Tilbury Docks were constructed for the East and West India Dock Company, and were the outcome of a long-felt need for increased accommodation for first-class steamships.

When the South West India Docks were constructed in 1870, from the designs of the late Sir John Hawkshaw, with lock-entrances of 55 feet in width and with 27 feet of water upon the sills at high-water of ordinary spring tides, it was considered that ample steamship accommodation had been provided; but only seven years later further enlargements were found desirable, and an extension of the East India Dock was carried out from the designs of Mr. A. Manning. This extension gave a limited area of first-class dock space, with river-entrances 65 feet wide and 32 feet in depth below high-water of ordinary spring tides. Subsequently, the East and West India Dock Company found that the exigencies of trade necessitated considerable extensions. Drawings were prepared by their engineer, Mr. A. Manning, for a further enlargement of the East India Docks; but it was decided not to proceed with the proposed extension on the ground that the principal difficulty lay not so much in accommodating the ships in the docks as in the River Thames itself, which is sinuous and shallow for about 20 miles below London Bridge, navigation being impossible for large steamships except at or near the time of high-water. Ultimately the Company determined to construct new deep-water docks several miles below any of the existing docks. The advantages offered by this course were many, the chief among them being the convenience of enabling the largest steamships to enter and leave the docks at any state of the tide, the avoidance of the dangerous navigation of the upper reaches of the Thames, and exemption from some of the heavy fogs which occur there.

Site.—The site selected for the intended docks occupies an area of nearly 500 acres of marsh land on the north bank of the Thames opposite Gravesend, lying in the angle formed by the London,

Tilbury and Southend Railway between London and Tilbury Pier. Though at a much greater distance from London than the existing docks, the railway facilities are exceedingly good, communication being obtained over the Tilbury Railway with all the railways north of the Thames.

The surface of the site was about 6 feet below the level of high-water of ordinary spring tides, and was protected on the river front by the embankment which forms a well-known feature of the lower Thames. The embankment proved of great service during the execution of the works, saving both the expense and the delay which would have occurred in building a cofferdam; and enabling the inside works to be practically completed before it became necessary to make a breach in the embankment to admit the water.

Excavation.—Preliminary borings showed the soil for a depth of about 6 feet to be brown fibrous clay, below which were alternate layers of blue-coloured alluvial clay and peat; the whole overlying a thick stratum of hard compact gravel. Below the gravel was hard chalk rock of indefinite thickness. The gravel was generally found at a level suitable for the foundations of the walls. The superincumbent soil was as a rule easily excavated, and owing to its impervious character, the trenches and general excavations were in most cases free from water until they reached nearly to the gravel. Crossing the site of the main dock, and trending in an easterly direction, the excavations exposed traces of a gully, presumably an old channel of the river, out of which the gravel had been scoured to a considerable depth, the chalk rock being laid bare in some places. To this old channel is to be attributed most of, if not all, the difficulties which were met with during the progress of the works. The soil in the gully, particularly below the general level of the gravel, was generally softer than the alluvial material. Fortunately the direction of the old channel was such that it did not seriously interfere with any considerable portion of the works, the south-west corner of the western branch dock, and the south side of the main dock being the principal parts affected.

The timbering of the trenches was of the character usually adopted in alluvial soil. In the general excavation and steppings in trenches, vertical faces, 10 to 15 feet high, were frequently left for long periods without support.

Arrangement of Docks.—The arrangement of the docks is shown in Fig. 1, Plate 4. The tidal basin, having an area of 17½ acres, is approached from the river through an open entrance 364 feet in

width, flanked by open timber jetties projecting into the river. On the north-east and south-east sides of the basin there are quays with half-tide landings, to enable passengers to disembark with their baggage before the ship proceeds to the berth in the inner docks. On the north side is a transhipment quay for the use of continental boats. A coaling-jetty is also provided in the tidal basin. The main and branch docks have a water-area of 52½ acres, with berth accommodation at the quays for thirty-one vessels averaging 400 feet in length. Each berth in the branch docks is provided with a shed, and has direct railway access to the London, Tilbury and Southend Railway, without the use of turntables or curves of less than 6 chains radius. The whole of the main and branch docks are quayed, with the exception of the south-west end of the main dock, at which point any future extension would probably be made.

The lock, between the tidal basin and the inner docks, has a total length of 946 feet, the lock-chambers being 555 feet and 145 feet long respectively, with a width of 80 feet, and a depth on the outer and middle sills of 44 feet below Trinity high-water mark. The graving-docks are parallel to the lock, and are of the same extreme length. They are entered from either end, and have a movable caisson in the centre, so that they can, if necessary, be used as entrances to the inner docks. The depths of the tidal basin, lock, &c., are so arranged that a ship drawing 23 feet of water can, even at low-water of spring tides, proceed direct to her berth in the inner docks.

Building Materials.—The material used for the walls of the quays, lock, graving-docks, &c., was principally concrete, composed of 10 parts of ballast to 1 part of Portland cement. The concrete-work was faced above low-water mark with blue bricks, having stock-brick backing—the whole being 9 inches in thickness, with half-brick piers about 4 feet apart dovetailing into the concrete. The facing for subaqueous work was generally of fine concrete, gauged 3 to 1, 12 inches in thickness, and carried up with the general walling. The ballast was dredged from the Thames, supplemented during the latter period of the works by pit-ballast from the neighbourhood of Pitsea. The Portland cement was obtained from manufacturers on the Thames and Medway, and was carefully inspected to ensure compliance with the specified conditions. The tensile strength required after seven days' immersion in water was 600 lbs. on a section measuring 1½ inch square.

The whole of the copings, sills, quoins, invert-stones, cutwaters, sluice-stones, and engine-foundations are of Cornish granite from

the Penrhyn district. Bramley Fall stone was largely used in the less exposed parts of the lock and the graving-docks, as well as in the pumping-station.

Preliminary Works.—It became necessary at an early period of the operations to intercept the Chadwell main marsh drain, which crossed the site from north to south, and was connected with numerous branch drains intersecting the site in all directions. A diversion of the main drain was formed, partly in cuttings and partly in culverts, along the eastern boundary of the site, having an outlet near the Tilbury railway station. This drain was subsequently completed by an extension in a westerly direction following the boundary of the property.

River Jetties.—The jetties at the entrance to the tidal basin are 45 feet in width, and project in the tideway into about 45 feet of water at high-water of spring tides, or 48 feet below Trinity high-water mark. The centres of the rounded ends of the jetties were formed of cast-iron cylinders, 15 feet in diameter, sunk to a chalk foundation at about 75 feet below the level of the deck. These cylinders were afterwards filled with concrete. Immediately around the cylinders, and hooped at intervals to them, was driven a double row of piles, from which radial- and cross-strutting was carried to the outer piles. The straight portions of the jetties were formed by a double row of piles on each side in 10-foot bays, with four horizontal struts, and cross-strutting the full width of the structure. The whole of the piles and main timbers were of pitch-pine sawn logs, and averaged about 14½ inches square, and 65 feet in length. The decks were formed of 3-inch planking in 4½-inch widths, laid upon 11-inch by 2-inch bearers. The shore end of the west jetty was similar in construction to the outer ends, and the corresponding end of the east jetty was connected with the solid knuckle formed by the return of the south wall of the tidal basin.

Tidal-Basin Quays.—The section of the wall used in the tidal basin for the transhipment wharf, between the entrances to the lock and the graving-docks, and at the north end of the north-east quay, is shown in Fig. 2, Plate 4. The walls of the east and west quays were intended to be of similar section for two-thirds of their height, and to be then carried up vertically at the back, allowing space for half-tide landings to be formed in the faces of the walls. Owing, however, to the foundation in this place being of sandy gravel, and a tendency being indicated to form boils in the excavation, especially at high-water, it was decided to construct the latter walls upon piled foundations.

On the south-west slope of the tidal basin a coaling-jetty, 170 feet in length and 20 feet wide, was constructed of open timber work. Four 30-cwt. movable hydraulic cranes, each provided with weighing apparatus, travelled upon rails along the deck. The jetty is connected to the bank by two wrought-iron lattice bridges supported on timber piers. The use of this jetty for coaling purposes has been discontinued, the machinery being used elsewhere in the docks

Lock.—The lock is shown in plan in Fig. 3. The walls of the lock, Fig. 4, are vertical, and were constructed of concrete gauged 10 to 1, faced with Staffordshire blue bricks to low-water mark, and below that level with stock bricks. The thickness of the walls at the base is 19 feet, diminishing to 8 feet at the top. The invert arch is of stock bricks in nine half-brick rings, the springers being of Bramley Fall stone worked out of blocks of about 16 feet sectional-area. The thickness of the invert in the lock-chambers is 8 feet 6 inches at the centre, and about 15 feet 6 inches at the outer and middle gate-sills. The walls of the lock were built in trenches, and the invert and sills were put in by cross trenching after the dumpling had been removed. The lock-gates are of wrought-iron, double skinned, each fold being 49 feet long. The outer faces are of 140 feet and the inner faces of 53 feet 6 inches radius. The effective height of the outer and middle pairs of gates is 44 feet, and that of the inner pair 38 feet; the width between the inner and the outer skins of the gates at the centre is 6 feet. The gates are each divided vertically into four watertight compartments, and are surmounted by a timber platform at the coping-level. The weight of the outer and middle gates is 330 tons per pair, and that of the inner gates 293 tons. The heel- and meeting-posts of the gates and the striking-sills are formed of greenheart, and the roller-paths, which have a radius of 32 feet, are of cast steel in 5-foot lengths bolted down to the granite track.

The lock-gates were designed to be ballasted with water, so that at high-water they should just bear upon the rollers and pivots. Pumps are provided for controlling the water-ballast, but it was not intended that this should be varied during tides in order to maintain equilibrium. The gates are in every respect of sufficient strength, and the hydraulic hauling machinery is of suitable power to work them if waterlogged—an event which might occur if one of the skins were damaged by collision. Twelve double-power hydraulic gate-machines of the "jigger" type, fitted in a horizontal position, are provided for opening and

closing the lock-gates. Twelve hydraulic sluice-machines of similar character to those working the lock-gates, but placed vertically in the sluice-shafts, are also provided. The paddles are of greenheart bolted to a cast-iron beam, which is connected to the crosshead of the piston. The culverts closed by these sluices have each a cross-sectional area of about 50 square feet. The lock is furnished with four 2½-5-ton double-power hydraulic capstans, and with cast-iron lip bollards, and check-posts.

Graving-Docks.—The graving-docks, Fig. 3, are arranged on a novel principle, forming practically passages between the tidal basin and the main dock. These docks are closed at their ends by ship caissons, and each is divided into two sections by a caisson capable of occupying any one of three separate positions in the dock. The result of this arrangement is the formation of virtually four graving-docks, each complete in itself, two being entered from the tidal basin, and two from the main dock. The lengths of the sections into which each dock can be divided by its central caisson are as follows:—450 feet and 400 feet, 500 feet and 350 feet, or 550 feet and 300 feet in the clear. The central caisson of each dock can, if necessary, be floated out to form a dock of about 875 feet in length. Four first-class steamers have been in these dry docks at one time, each being quite independent of the others as to time of arrival and departure. The large graving-docks have a width of 70 feet across the bottom, and a depth of 35 feet below Trinity high-water mark on the sills. The corresponding dimensions of the small graving-docks are respectively 60 feet and 30 feet.

The walls of the large graving-docks, Fig. 5, have a thickness of 16 feet 3 inches at the floor-level, and of 5 feet at the coping. The backs of the walls are vertical, except where it was necessary to increase the width for culverts, and the internal faces of the walls have a batter of 1 in 20 for a height of 22 feet 6 inches. The upper part of the walls are stepped to form six altars. The thickness of the invert varies with the depth to which it was required to excavate to reach the gravel foundation, but the normal thickness is 15 feet. The walls of the small graving-docks, Fig. 6, are 13 feet 6 inches thick at the base, and their other dimensions are in general smaller than those of the walls of the large graving-docks in the same proportion. The invert is, however, relatively thicker, on account of the necessity of excavating the foundations to the same depth in both cases. A portion of the invert of the small docks is, owing to a dip towards the old channel previously mentioned, carried upon short

whole timber bearing-piles spaced at 4 feet centres in each direction. The invert is entirely of 9 to 1 concrete, with a stop-water course 3 inches thick, of fine 3 to 1 concrete, as shown in Figs. 5 and 6. Upnor clay puddle 1 foot 6 inches thick is carried down the backs of the graving-dock walls from Trinity high-water level to below the stop-water course. The floors of the graving-docks are of pitch-pine planking 4 inches thick, spiked down to pitch-pine sleepers 14 inches square, which are bedded in concrete. Teak keel-blocks are laid along the whole length of the docks, and are fixed down to the floors by dogs. The altars are paved with 6-inch hard York stone, the copings being of teak 12 inches square, furnished with eye-bolts and secured to teak cross-timbers 3 feet 6 inches long, bedded in brickwork at the tops of the walls.

The graving-docks are provided with five hydraulic capstans similar to those already described for the lock, and cast-iron upright bollards. The bollards, which have perforated caps, are connected by pipes to the various culverts, and thus serve as outlets for the air, when the culverts are in use. Each of the four sections of the graving-docks has a distinct set of culverts for running out and filling in the water, and the pumping arrangements allow of pumping the water out of any one section into any other section, or, through the discharge-pit in the rear of the engine-house, into either the main dock or the tidal basin.

The machinery at the graving-dock pumping-station consists of four centrifugal pumps, two with fans 5 feet in diameter, and two with fans 4 feet 6 inches in diameter. These are driven by four sets of engines of inverted direct-acting high-pressure type, two with cylinders 22 inches in diameter and 16½ inches stroke, and two with cylinders 17¾ inches in diameter and 16½ inches stroke, for the large and small pumps respectively. The pumps are together capable of discharging 650 tons of water per minute into the discharge-pit, and therefore of pumping out the large pair of docks in about one hour. Two distinct sets of double-acting plunger-and-bucket pumps for drainage, each capable of raising 1,000 gallons per minute into the main dock, are provided. The engines driving them, through gearing, are of horizontal type. Steam is raised from five boilers, one being spare, of modified marine tubular type, 7 feet 6 inches in diameter, and 20 feet long, with two flues 3 feet in diameter. The flues lead to wrought-iron chimneys, one for each boiler, and thus an ordinary shaft is dispensed with. Forced draught is driven through the stoke-holds by five fans, each with a small independent engine. A cast-iron tank, of 250,000 gallons

capacity, into which water from the drainage culverts is pumped by an auxiliary engine, covers the boiler-house.

Caissons.—The caissons were constructed of iron with greenheart stem- and keel-timbers, and with three watertight decks, arranged for water-ballast. Their top portions are in addition divided vertically into three watertight compartments. All the caissons are of ship form, the two at the main-dock entrances fitting against stop-faces, the other four fitting into caisson-grooves. The two caissons at the tidal-basin entrances were erected in their grooves, to allow of the water being let in to the tidal basin if required, before the inner works were completed, but the other caissons were launched from the builder's yard at Blackwall and floated down to the docks. The effective height of the caisson closing the tidal-basin end of the large graving-dock is 39 feet 6 inches, and its effective length is 70 feet on the keel, and 78 feet 10½ inches at the coping. The corresponding caisson of the small graving-dock has an effective height of 34 feet 6 inches, and length of 60 feet on the keel, and 67 feet 10½ inches at the coping. The caissons at the end of the main dock are similar to those first described, but as there is a difference between the batter of the stop-face and that of the caisson-grooves, they are not so long at the coping line. The central caisson of the large graving-dock has an effective height of 36 feet 6 inches, and an effective length of 69 feet 3 inches at the bottom and 78 feet at the coping. The central caisson of the small graving-dock is generally similar to that of the large dock, but its depth is 5 feet and its width 10 feet less. All the caissons have a beam of 22 feet, and are furnished with a deck 10 feet wide at the coping-level. The weight of these caissons is together 1,455 tons, exclusive of kentledge for ballast.

The caissons are worked by means of water-ballast tanks and compartments. When the water in the upper tank above the outside water-line is run off, the caisson rises sufficiently to allow the lower water-ballast compartments to empty themselves in succession. The caisson rises in consequence sufficiently high (about 9 feet) to clear the grooves. For sinking the caisson into position, water is let into the tank and compartments by means of a hose-pipe connected to the water-mains along the quays. No pumps are required either for filling or emptying the water-ballast.

Main and Branch Docks.—The inner docks were constructed to be of a uniform depth of 38 feet below Trinity high-water mark, or 42 feet 6 inches below their coping-level. The walls of the main

and branch docks are similar to those of the tidal basin, Fig. 2, but of somewhat smaller dimensions. They were carriod down to the gravel formation, generally about 4 feet below the bottom of the dock, and are 19 feet thick at a height of 2 feet above the bottom of the dock, with a projecting toe 3 feet wide. The walls have a batter of 1 in 20 on the face, with set-offs at the back reducing their thickness at the coping-level to 6 feet. They are throughout coped with slabs of granite 2 feet 6 inches wide and 1 foot 6 inches thick, in lengths of not less than 4 feet. No. 11 and part of No. 12 quay at the south-west end of the western branch dock were constructed in the line of the old river channel, and piled foundations were here rendered necessary, the toe being supported by whole timber sheeting piles, with bearing piles spaced with their centres about 4 feet apart under the wall and counterforts. In the case of the main dock walls, which were constructed partly in the line of the old river channel, piling was unnecessary, as the gravel foundation was reached at a depth of between 2 feet and 6 feet below the normal depth of the branch dock quay-wall. The quay-level of the docks is in general about 12 feet above the original surface of the site, so the whole of the excavated material (about 4,500,000 cubic yards) was used in making up the quays to the level required. This filling was selected and well rammed in layers behind the walls, and the remainder tipped over the area to be raised.

The branch docks are arranged to admit of the prompt loading and discharge of cargo, two lines of rails, connected between each quay-shed by a scissor-crossing, being laid along the quays, one as a working line, the other as a standing line for each berth. Similar lines and crossings are arranged immediately behind each quay-shed. The haulage of trucks at the north ends of the branch docks (and to the tidal-basin quays) is done by light engines, and at the south ends of the branch docks by 1-ton hydraulic capstans. Except at the north side of the main dock, direct lines, without the use of turntables, are provided. Along the branch-dock quays crane-roads are laid, and upon these fifty-six 30-cwt. hydraulic cranes, with high pedestal bases, to allow engines and loaded wagons to pass beneath them, travel. These cranes are fitted with telescopic connections so that they can work at any desired point along the crane-road. The hydraulic valves for supplying power to the cranes are spaced at distances of about 28 feet apart along the quays. Two large lip bollards for mooring ships are provided for every berth, and mooring rings for barges are recessed in the faces of the quay-walls, at

distances of 200 feet apart. Fresh water is distributed along the various quays by 5-inch water-mains, fitted with stand-pipes and fire-hydrants, at intervals of about 400 feet and 180 feet respectively.

Quay-Sheds.—The twenty-four berths in the branch docks are each provided with a quay-shed 301 feet long and 120 feet wide, giving a floor-area of over ¾ acre, the roofs being constructed in two spans of 60 feet. The sheds are constructed with timber story-posts, iron roof-principals, and boarded and slated roofs.

The front and the back of each shed, for 240 feet of its length, are entirely open, but can be closed at will by steel self-coiling revolving shutters, working between the story-posts supporting the roof. When these shutters are open, free access is afforded between the quay and the railway in the rear of the sheds, and when they are closed the requirements of the custom-house for the safe custody of bonded goods are complied with. The ends of each shed and the small portions of the front and back not closed by the shutters are covered with corrugated iron supported upon timber framing. Well distributed light for the interior is obtained through 480 large glass slates in the roof of each shed. The floors of the sheds are of pitch-pine planking, laid upon sleepers bedded upon a layer of ballast 12 inches thick. Quay-sheds generally similar to those for the branch docks, but of one 60-foot span, are provided for the berths in the tidal basin. There are also sheds at the transhipment quay, at the east quay and at the south quay.

Hydraulic Power.—The whole of the outdoor machinery, consisting of cranes, capstans, lock-gates, sluices, &c., is worked by hydraulic power generated at the pumping-station at the north end of the docks. The water is pumped by three pairs of horizontal compound surface-condensing pumping-engines, each of 100 I.HP. Each pair of engines is mounted upon one bed-plate, but so that each single engine can be used separately and independently of the other. The engines were designed to deliver together, when running at 35 revolutions per minute, 30,000 gallons per hour against an accumulator pressure of 750 lbs. per square inch. The steam for these engines is supplied from three Lancashire boilers each 27 feet long and 7 feet in diameter. There are two accumulators at the pumping-station, each 20 inches in diameter and 24 feet stroke; and at the north-east and north-west corners of the tidal basin two independent accumulators of 17 inches diameter and 17 feet stroke have been erected to equalise the pressure over the whole system. The hydraulic engine-room is 100 feet in

length and 42 feet in width, space being provided for a fourth pair of engines, and a pipe-floor extends under its whole area. About 6,200 yards of 5-inch, and 1,900 yards of 4-inch cast-iron pressure-mains have been laid to transmit the power to the several cranes, capstans, &c., along the quays. The chimney shaft has a total height of 120 feet.

Foot-bridge and Buildings.—A foot-bridge over the various railway lines, 760 feet long, and constructed of lattice-girders in spans of about 50 feet supported upon channel-iron columns, has been erected to give communication between the offices and canteen at the north end of the branch docks and the Tilbury Dock Station. Among the various buildings which have been erected in connection with the docks are:—The hotel, designed by Mr. A. E. Gruning, F.R.I.B.A., overlooking the river and tidal basin, the north canteen, houses overlooking the river for the principal officers, thirty semi-detached cottages for foremen, &c., blocks of workmen's dwellings, engineer's offices, workshops, stores, locomotive sheds, and other smaller buildings.

No ordinary dock warehouse has been erected, but a goods depôt is provided at Whitechapel for goods passing through London to the docks, and for the showing and storage of goods landed at them. This warehouse, which is in direct railway communication with the docks, is four stories in height, and has a floor space of 11 acres.

Lighting.—The whole of the quays, railways, sorting sidings, &c., are lighted by eighty arc-lamps each of 3,000 candle-power, and the sheds, &c., by 1,362 glow-lamps of between 16 and 32 candle-power. The dynamos generating the current are driven by five engines of 500 effective HP., in two separate engine-houses. The lighting-plant was constructed and erected by Messrs. Crompton & Co., under the joint supervision of Dr. John Hopkinson, F.R.S., and the engineers to the docks.

Railway Communications, &c.—At the north-west corner of the dock property the Dock Company's lines are connected to the London, Tilbury and Southend Railway Company's system. Sorting sidings are provided at the north end of the dock lines. The rails at this place are of bulb-headed section, and weigh 80 lbs. per lineal yard. The dock lines proper are of Vignoles section, weighing 56 lbs. per lineal yard. For the sidings and dock lines a total length of about 22 miles of single line has been laid. A sorting shed, with three lines running through it, 250 feet long and 60 feet wide, has been erected to admit of the dividing up of truck loads of small goods having destinations in various parts of

the docks and *vice versâ*. Another connection with the Tilbury Railway, chiefly for conveying passengers to and from the tidal-basin quays, is made near the Tilbury Station. Access is obtained over the same company's railway system to all the main trunk lines north of the Thames viâ Barking, Bow or Plaistow, and with the existing docks belonging to the East and West India Dock Company viâ Stepney.

Specially constructed lighters enable goods for conveyance to the railway wharves south of the Thames, the upper docks or elsewhere, to be delivered or received alongside ships in the docks.

Floating-Plant.—The three principal items of floating-plant constructed under the supervision of the engineers are the tug, the dredger, and the floating-crane. The tug is used for taking ships in and out of the docks. It was constructed for the highest class at Lloyd's, and has an iron hull, 80 feet long, 18 feet beam, with a draught of 7 feet, and is propelled by twin-propellers. Each propeller is driven by a separate compound-engine, the two engines together developing 200 I.HP. The tug is fitted with independent fire-engines, having four 1¼-inch deliveries.

The dredger is of the central ladder type, arranged to make 45 feet of water at an angle of 35°. The hull is 101 feet long, 20 feet beam, and has a draught of 8 feet. This vessel was completed by Messrs. Hunter and English some considerable time before it was required in the docks, and it was used during the progress of the works in raising ballast from shoals in the river for concreting purposes, and finally assisted to remove the river embankment across the entrance to the tidal basin. The dredger, when so engaged, has raised 210 cubic yards of material per hour.

The floating-crane, also built by Messrs. Hunter and English, was designed to lift loads of 50 tons and swing them at 25 feet radius, or loads of 45 tons at 30 feet radius. The hull is of iron, 110 feet long, 44 feet beam, with a draught of 9 feet, and is fitted with two transverse watertight bulkheads, and a central bulkhead under the roller-path. This vessel is propelled by twin-screws, at a maximum speed of about 4½ miles per hour.

Subsequently to the opening of the docks, an additional dredger was provided, principally for use in the tidal basin, but also available in the lock and in other positions where an ordinary dredger could not be operated. This machine consists of a tug-boat provided with a steam pumping-engine, and a harrow or rake attached to its stern. The hose-pipe deliveries of the pump terminate in nozzles which can be suspended near the

dock-bottom. This water-jet machine, working for a few hours on the ebb-tide, is able to drive out into the river any mud-deposit that may have been left by the flood-tide. The ladder-dredger already mentioned has been found amply sufficient for the work required of it in the main and branch docks.

The Act of Parliament sanctioning the construction of the Tilbury Docks received the Royal Assent on the 3rd of July, 1882, and on the 8th of the same month the first turf was cut by Mr. Harry H. Dobree, the then chairman of the Company. A provisional contract had already been entered into, and the work was commenced immediately. In July, 1884, however, the Company resolved to take over and itself carry on the work. In October of the same year a fresh contract was entered into with Messrs. Lucas and Aird, by whom the docks were completed. The docks were opened on the 17th of April, 1886.

The engineer to the company was Mr. Augustus Manning, and the designs for the works were prepared by him in conjunction with his partner, Mr. Donald S. Baynes, M. Inst. C.E., the Author being their chief assistant. Mr. Baynes acted as resident engineer while the works were in progress. Mr. William Colson was the agent for Messrs. Lucas and Aird, the principal contractors.

The Author desires to express his obligation to Mr. Augustus Manning and to Lt.-Col. J. L. Du Plat Taylor, C.B., for the use of drawings and information contained in this Paper, the preparation of which has been delayed by lengthy legal proceedings in which the company was involved.

The Paper is accompanied by two lithographs and three sheets of drawings, from which Plate 4 has been prepared.

(*Paper No. 2851.*)

"Ardrossan Harbour Extensions."

By Robert Robertson, B.Sc., M. Inst. C.E.

Ardrossan is situated on the Frith of Clyde, about 50 miles below Glasgow. The present site of the harbour, a series of rocky crags, has for the greater part been reclaimed from the sea. Early in this century Mr. Telford made a survey of the bay at Ardrossan, with the view of constructing a harbour, to be connected by a canal about 30 miles long directly with Glasgow. The works proposed at the time of their commencement in 1806 were: (1) An outer harbour sheltered by a breakwater, wherein ten or twelve vessels might lie at anchor, or wait before entering the dock, in a depth of water of between 20 feet and 30 feet at high water; (2) A tidal harbour for fifty to sixty coasting vessels, with a depth of between 10 feet and 20 feet at high water; (3) A dock of about 4 acres, to accommodate thirty large vessels of 300 to 600 tons, with a depth of water of 20 feet; (4) A graving dock for repairing vessels.

The work progressed very slowly; and the dock, having 1,500 feet of quayage, and a lock 155 feet long and 38 feet wide, with three pairs of gates, was not opened for traffic until 1845. The graving dock, completed at the same time, is 260 feet long and 38 feet wide; and the repairing slip has a carriage 150 feet long, Fig. 1, Plate 5.

After this dock had been in use for about twenty years, the gradually increasing size of vessels and the development of shipping indicated the necessity of soon extending the harbour to maintain the trade. In 1864 sanction was obtained for the construction of a new dock, a tidal basin, and a breakwater. The extension works, however, were not undertaken until 1884, when the construction of the Lanarkshire and Ayrshire Railway, connecting the coal-fields of Lanarkshire with Ardrossan, was under consideration. The expenditure upon the works up to 1884 amounted to upwards of £200,000. Under the Act of 1886, transferring the harbour from the Earl of Eglinton to a Company,

power was taken to raise £200,000 for carrying out the extensions to accommodate large steamers.

More than two hundred and thirty borings were made over the site of the excavations and walls, whereby the quality and quantities of material to be removed, and the nature of the foundations, were accurately determined, as proved by the works, commenced in May, 1887. These works comprised a dock of about 10 acres, a tidal basin of about 5 acres, now called the Eglinton Dock and Basin, a breakwater about 1,330 feet long, and the deepening of the entrance channel over an area of 14 acres.

Cofferdams.—Cofferdam A, Figs. 1 and 2, Plate 5, was commenced in May, and closed in August, 1887. Considerable difficulty was experienced in making this cofferdam watertight at its junction with the existing quay-walls, owing to leakages under the foundations of these walls at each end. This was remedied by sheet-piling along the front of the wall, outside the cofferdam, for 50 feet or 60 feet, and filling in between the sheet-piling and the wall with clay and concrete, which reduced the influx of water sufficiently to enable it to be kept under by pumping. The leakage was much greater at high water than at low water, and at the maximum, required a 6-inch centrifugal pump working constantly to keep it down. The old Montgomerie pier, about 30 feet wide, consisting of a vertical wall on the dock side and a pitched slope on the outside, also gave some trouble with leaking. It had ultimately to be sheet-piled at the back along the toe of the pitching, which was carefully pointed to render it watertight.

During an exceptionally high tide on the 1st November, 1887, a portion of the cofferdam, 150 feet from the south end, was broken through, and the area inside flooded. The tide on that day rose 4½ feet above ordinary high-water level of spring-tides, Fig 2, and shortly before high water, the cofferdam began to leak below the sheeting at the point where the breach ultimately took place. An unsuccessful effort was made to stop this leak with clay and straw; but it gradually increased, till at about high water, 60 feet of the cofferdam was carried away. The failure of the dam was evidently due to the want of diagonal bracing, as it gave way through the frames becoming distorted. The depth of water against the cofferdam at the time of the accident was about 20 feet; and the rush of the water was so great, having to fill an area of 13 acres to an average depth of 13½ feet, that for a length of nearly 200 feet opposite the breach, a trench was partly cleaned out down to the rock; large masses of solid rock (some weighing several tons) were thrown up on each side, and smaller rocks and boulders were

carried far into the enclosure. The breach in the cofferdam was repaired in four weeks; the cofferdam was strengthened throughout its whole length by diagonals and shores, with additional stone-filling, Fig. 2.

The next cofferdam, commenced in August, 1887, and completed in January, 1888, not having to resist a great pressure of water, was constructed of vertical sheet-piling. The first 60 feet at the east end of this cofferdam were made double; but the rest was piled on the outside only, and the piling closed in at the end against the embankment. This cofferdam and the wall within it were constructed by means of a crane on a travelling platform; but owing to numerous delays due to leakages the wall was not completed until May, 1888.

The cofferdam for the extension of Montgomerie pier, Figs. 1 and 8, was commenced in December, 1887, and completed in September, 1888. Work was carried on within this cofferdam until 16th November, 1888, when a great portion of it was destroyed by a heavy storm, and it was not closed again until January, 1889.

Cofferdam B was commenced in March and completed in July, 1890, Figs. 1 and 3; but its closing was delayed till the completion of the new wall on the west side of the tidal basin, in February, 1891. Box cofferdams, made in lengths of between 60 feet and 100 feet, were used for the construction of the walls on the west and south sides of the tidal basin, Fig. 7.

Cement.—The cement used in the works was of London manufacture, leaving a residue not exceeding 15 per cent. on a sieve of 2,500 meshes per square inch, and weighing not less than 90 lbs. per cubic foot, filled from a spout at an angle of 45°, and striked. The tensile test was 790 lbs. on briquettes with a section of 1½ square inch after seven days, during the last six of which they were immersed in water. The cement, on delivery, was spread out in a layer between 3 feet and 4 feet in depth, and when necessary for cooling, it was turned over periodically before being used.

Concrete.—The ballast for concrete consisted of hard stones broken by a machine to pass through a screen with meshes 2 inches wide, and of gravel and coarse-grained sea-sand. The proportions for rubble concrete were 2 of broken stones, 1·4 of gravel, 2·2 of sand, and 1 of cement: the proportions for concrete in bags were 2·2 of broken stones, 1·6 of gravel, 1·2 of sand, and 1 of cement. The concrete was mixed in McKinnel or other approved mixers; and where hand-mixing was allowed, the cement and ballast were turned over together four times dry on a wooden platform, and then four times while water was added through a

rose. The ballast for the concrete for blocks consisted of boulder stones taken from the beach, broken to pass through a 1½-inch screen, and coarse-grained sand. The concrete, consisting of 2·1 of broken stones, 1·35 of sand, and 1 of cement, was tipped into smooth-dressed moulds, rammed in layers, and finished smooth on the top, the top being finished off with neat cement grout before the concrete had set. The blocks were kept in the moulds for at least four days, and were not disturbed within one month.

Rubble Concrete.—This was composed of concrete, as described, amalgamated with clean, hard rubble stones, placed not less than 3 inches apart, nor within 6 inches of the framework. The work was carried out in level courses, not exceeding 2 feet in height, and not less than 20 feet in length, and with only one rubble stone in depth in each course, laid on a 6-inch bed of concrete, beaten down to a solid bearing, and packed and covered with concrete. The rubble stones were laid within two hours of forming their concrete bed; and the framing was not removed till the rubble concrete was four days old.

Concrete in Bags.—The concrete was filled into a hopper lined with strong double-warped jute bagging, weighing 20 ounces per square yard for quay-walls, and 24 ounces per square yard for the breakwater; the concrete was well rammed with thin sword rammers. Only two courses of bags were laid in one day, and nothing was built on them for four days.

Eglinton Dock.—This occupies a portion of the site of the old tidal harbour, which has been divided in two by a pier, 80 feet wide, forming the boundary between the dock and the tidal basin. The depth of water in the dock is 27 feet at high water of spring-tides, and the quay is 8¾ feet above that level. The portions of the north and south walls of the old tidal harbour, extending along the side of the new dock, were retained; but having been founded on clay, they were under-built to the rock with rubble concrete, to a depth varying between 2 feet and 20 feet, Fig. 4. The clay below the walls was excavated back 5 feet from the face of the wall, and the front of the wall was supported from the rock by raking shores. The rubble concrete under-building has a uniform thickness of 5 feet where the depth is less than 10 feet; but for greater depths, the under-building is 6 feet thick at the top, increasing downwards with the batter of the wall. The excavation was taken out in alternate lengths of about 10 feet, and the clay left between until the blocks on each side were thoroughly set; then the intermediate spaces were excavated and built up The rubble concrete was built in layers of about 18 inches or

2 feet, until too close to the underside of the old walls for men to go in below; it was then built from the front, and the concrete carefully rammed into the back. When the concrete was within 1 inch or 2 inches of the underside of the wall, an additional board, bevelled outwards, was put on the front of the frame; liquid grout of cement and sand poured in, filling up the small space between the concrete and the wall. This proved most satisfactory, as shown by an examination of the side of each block on excavating the intermediate space. No trouble was experienced in supporting the walls, and no settlement took place during the under-building.

The east wall of the new dock was constructed entirely of rubble concrete, and, with the exception of a portion of the north end, was founded upon rock. Where the rock was above the dock-bottom, the rock-face was sheared down in continuation of the batter of the wall, Fig. 5. Where the rock-face was at all loose or brittle, a 12-inch facing of concrete was put on to protect it. At the north end of this wall, and the east end of the north wall, the rock proved unsuitable for building upon. It was accordingly excavated down to the dock-bottom for a width of 6 feet, was built up to the top of the rock with rubble concrete, and the wall completed to the quay-level on the top. The walls on both sides of the pier, between the dock and the tidal basin, were constructed of rubble concrete as far as the rock, which was sheared down, like the east wall of the dock, Fig. 5, except where the surface of the rock was below dock-bottom, Fig. 6. All the walls inside the cofferdam A were constructed within framing, in lengths of about 30 feet, with vertical joints from top to bottom; in the centre of these joints a V-shaped recess was formed throughout the whole height, preventing lateral displacement of any section. The frames were shifted from stage to stage, and from length to length, by 3-ton steam derrick cranes, erected behind the walls. The concrete mixers and mixing platform, stone breakers, &c., were set up permanently, the mixed concrete being conveyed on bogies to the sites required, in iron hopper boxes containing about ¾ cubic yard.

The depth of the excavation to the dock-bottom varied between 33½ feet to 13 feet; the quantity removed amounted to 110,620 cubic yards of soft soil, and 196,110 cubic yards of rock. The soft soil consisted largely of coarse sandy clay, with a few boulders of varying sizes, there being a thin surface covering of sand and silt. The rock excavated varied in thickness from 28 feet down to nothing in some parts; that on the side of the tidal basin and Eglinton Dock, belonged to the lowest division of the car-

boniferous formation, and dipping in a south-easterly direction from about 1 in 12 at the west end of the tidal basin, to about 1 in 1 at the south-east corner of the dock, varied greatly in character. Throughout the tidal basin, for about one half the length of the dock, the rock was a coarse-grained sandstone of various colours and hardness. Towards the east end of the dock, these sandstones were overlaid by a 2-foot bed of red volcanic ash, followed by other beds of sandstone, over which was a bed of magnesian limestone between 15 feet and 20 feet thick. Overlying this limestone was a series of thin-bedded limestones interspersed with various coloured shales, and then darker shales and thin beds of clay ironstone. Next came a bed of dark red sandstone, over which were masses of volcanic agglomerate. These beds were much decomposed, and the cavities filled up with calcite, there being a number of small faults throughout the formation. The excavated materials were used for forming the quays, and for making up the ground in front of Montgomerie Street, being hauled up an incline by a winding engine, and tipped in the various embankments.

Dock Entrance.—The walls of the entrance were founded on rock excavated 4½ feet below the sill, which is level with the bottom of the dock and tidal basin; the gate-floor is 18 inches lower than the sill. The sluices on each side of the entrance are 3 feet wide and 4 feet high, with inlet sluices 2 feet wide and 2 feet high at the bottom of the gate-recess. The sill stones, hollow quoins, and sluice-chamber guides, are of granite; the rest was built in rubble concrete, except the sill, gate-floor, and aprons, which are of concrete.

Tidal Basin.—The east wall of this basin was constructed of rubble concrete inside cofferdam A, like those of the dock, Figs. 5 and 6. The south and west walls were constructed of rubble concrete within box cofferdams, Fig. 7. The walls round the basin were founded between 8 feet above and 3 feet below dock-bottom. The excavation in the tidal basin consisted of 67,770 cubic yards of soft soil, and 24,033 cubic yards of rock, and varied in depth between 14½ feet and 9 feet. The maximum depth of rock was 9 feet; over a considerable area it dipped below dock-bottom. The excavation within cofferdam B was taken out dry, conveyed through the dock and up the incline, and deposited on the reclaimed ground in front of Montgomerie Street.

Montgomerie Pier.—The walls of this pier were constructed dry within cofferdams. The inner portion, which served as a retaining wall for the embankment, was constructed within two rows of

timber sheeting; the outer portion was built as shown in Fig. 8. The depth of sand overlying the clay and rock in some portions of the latter wall was so great that the foundation was timbered on each side and the wall built within a trench. After the walls were completed the trench was widened and the excavation was removed as close as possible to the cofferdam, to save blasting and dredging under water.

Winton Pier.—The new wall at the end of this pier was built of concrete deposited in bags, as originally proposed for all the walls outside cofferdam A. The site of the wall was dredged as clean as possible to the rock by a small dredger; the rock was cleaned and sloped back 1 in 12 by divers and men working in the diving-bell. The bags were then laid in the same manner as those of the breakwater. When the bags reached 2½ feet above low water, frames were erected on the top, and the rubble-concrete superstructure built in lengths of about 20 feet. Each length was carried up in one tide, being kept in advance of the rising tide, Fig. 9.

Breakwater.—The section of the breakwater at its maximum depth, Fig. 10, was constructed up to 2½ feet above low water with concrete in bags. This concrete was mixed in two continuous blade mixers erected on the shore close to one of the quays. The mixers deposited the concrete through long shoots into wooden boxes, about 27¾ feet by 6 feet by 4 feet, laid on steam lighters. Jute canvas bags of the requisite size were placed in the boxes, with a lid in two sections, which was sewn up while the lighter was steaming to the site of the breakwater. The box with the concrete bag was then lifted from the lighter by overhanging sheer-legs on a barge, and lowered into position; at a signal from a diver, the doors at the bottom of the box were opened and the bag dropped into its place. Each bag formed a header the full thickness of the breakwater, the largest bags being 28 feet long and containing between 40 tons and 50 tons of concrete. As the work advanced and shorter bags were required, the box was gradually reduced in length by sliding false ends in it to the proper distance apart. The concrete for each bag was mixed in from three-quarters of an hour to an hour and a half; in most cases the bags were deposited in position within two hours after the commencement of the mixing of the concrete. This work could only be carried on in favourable weather, and during certain portions of the year. Three bags were laid in October, 1887; then the work was stopped till July, 1888, when the work was continued regularly, with occasional interruptions for clearing the new foundations, and on account of storms. In 1889

a start was made in March, and the work continued until October; in 1890, bag-work was commenced in April, and was finally completed early in December. The number of bags laid in the breakwater was 886, the average number laid per day was four bags, and the maximum more than double that number. The quantity of concrete deposited in bags, as measured in place in the breakwater, was 17,740 cubic yards, equivalent to an average of 20 cubic yards, or about 34 tons, per bag.

After the bag-work was completed for a considerable length, the rubble-concrete superstructure was built up in lengths of about 20 feet, within timber frames, lined with smooth boarding, and bolted to 12-inch balks, fixed by bolts and wedges to the bags. The concrete was mixed on shore, filled into hopper boxes placed on steam barges, and conveyed to the breakwater. A 3-ton steam derrick crane, on a large barge, was moored alongside the breakwater, by which the concrete and stones were deposited. This work was more subject to stoppages than the bag-work, as, besides requiring favourable weather, it could not be carried on during frost, even with a calm sea. In August and September, 1889, the first 160 lineal feet were constructed; between May and November, 1890, 640 lineal feet were added; and the final length of 530 feet was carried out from April to July, 1891.

Entrance Channel.—The deepening of the entrance channel was effected by dredging, the maximum depth of the excavation being 20 feet, and the maximum depth of rock 7½ feet. Most of the soft soil was first removed, the rock was then blasted from above water and removed by the dredgers. The boring was done through the well of a small old dredger; eight sets of ordinary boring tools were in operation at one time, 6 feet apart, in one row, being guided in wrought-iron tubes. After the holes reached a depth of 18 inches below the finished formation level, a charge of gelignite, in a tin case, with a long fuse attached, was placed in each of the holes; the fuses were then lighted, the tubes withdrawn, and the barge drawn to one side. The quantity of gelignite used varied according to the depth of the holes, averaging about ⅓ lb. per foot of depth, which amounted to about 1½ lb. of gelignite per cubic yard of rock blasted. The whole area of rock to be removed was blasted in this way, with blasts in squares 3 feet apart. In addition to the old dredger, two rafts were used, each raft carrying four sets of borers, consisting of four men each; the usual work done by one set was twenty-seven holes per week, or about seven holes per week per man, with an average depth of about 4½ feet. The average quantity of rock displaced by each

blast was about 1 cubic yard. The dredged area is shown by the dotted lines, Fig. 1; the portion of that area where rock was blasted being 20,800 square yards in extent. Considerable difficulty was experienced in some places where the rock was hard, in removing it after blasting; and several portions had to be re-blasted before the dredgers could remove it. The rock proved too soft to be broken up by square steel-pointed rods driven into it by steam-power.

Dock-Gates.—The dock entrance is 60 feet wide, and 63½ feet between the centres of the heelposts of the gates; the rise of the gates is 11¼ feet. The gates are of greenheart, each leaf being 34 feet 1 inch long, and 29¾ feet high, Figs. 11 and 12. In order to secure the gates against waves in stormy weather, strut-gates open out against the back of the main gates when closed, and wedge them against the sill, Fig. 11. They are 30 feet 1 inch long and 14½ feet high, and consist of a vertical post at each end, four horizontal bars, one diagonal, and one vertical strut, all of greenheart timber 12 inches × 12 inches.

Timber Wharf.—To enable two steamers to sail from the north side of Montgomerie Pier, a wharf was built in front of the retaining wall, thus allowing the steamer at the inside berth to pass the other freely, Fig. 1. This wharf was constructed of greenheart piles and old permanent-way rails, with pitch-pine beams and flooring, and elm fenders.

Mooring Palls.—Mooring palls of cast-iron, weighing 12 cwts., are built into the concrete walls round the dock and piers, about 50 feet apart. The walls are carried up the full thickness from the upper step for 6 feet opposite each mooring pall, Fig. 8.

Hydraulic Machinery.—The gates, hoists, cranes, and capstans round the new dock are worked by hydraulic power, generated by two pairs of horizontal, compound, non-condensing, steam pumping-engines, with high-pressure cylinders 18 inches in diameter, low-pressure cylinders 32 inches in diameter, and a stroke of 2 feet. The pumps are direct-acting and connected to the pistons, and can deliver 200 gallons of water per minute for each pair of engines, against an accumulator pressure of 750 lbs. per square inch, working with a steam-pressure of 80 lbs. per square inch, supplied by three steel Lancashire boilers, 26 feet long and 6½ feet in diameter. The accumulator is 18 inches in diameter with a 20-foot stroke, and is loaded to give a working pressure of 750 lbs. per square inch. Pressure pipes between 6 inches and 2 inches, and return pipes between 7 inches and 2 inches in diameter, are laid all along the east and north sides of the dock,

also to both sides of the entrance. The water is returned to a tank in the engine-room, of 2,000 gallons capacity, from which it is re-pumped into the pressure main.

Coal-Hoists.—Loaded coal-wagons are received by two hoists at the level of the quay; after being lifted and emptied into the shoot, they are run off on to a bridge 12 feet above the quay, turned on a turntable, and run down a viaduct by gravity on a gradient of 1 in 70. The hoists can lift a gross load of 18 tons to a height of 26 feet. The lifting ram is 12¼ inches in diameter, and the tipping ram 9 inches in diameter. Each hoist is provided with a crane for lifting a box containing 3 tons of coal a height of 50 feet, and also with a 20-cwt. capstan and snatch heads for working the wagons. The hoists can maintain a speed of fifty-eight wagons per hour so long as the holds will receive the coal without trimming.

Hydraulic Cranes and other Machinery.—There are six hydraulic travelling cranes capable of lifting 3 tons to a height of 50 feet. Three on the east side of the dock are raised high enough to allow wagons to pass underneath; the three on the north side are on the quay-level, with the wagon roads behind. A 5-ton hydraulic capstan at the north-east corner of the dock serves for travelling the cranes, also for warping vessels in the dock; there is another similar capstan on the south side of the entrance. The entrance is spanned by a two-leaved swing foot-bridge, which is turned by hydraulic power. A 30-ton steam-crane was erected, instead of a hoist, on the south side of the dock, there being no room for high-level lines; this crane is used for coal shipping and general work. The new portion of the harbour is lighted by twenty arc-lamps of 3,000 candle-power each.

No failure of any of the permanent works took place either during construction or subsequently; and all the works are standing wear and tear well. The works were completed, and the dock and tidal basin opened for traffic in June, 1892; they cost, including equipment, over £200,000.

Mr. John Strain, M. Inst. C.E., designed and carried out the extension works; the Author assisted in the preparation of the plans, and was Resident Engineer during construction.

The Paper is accompanied by twelve tracings and a drawing, from some of which Plate 5 has been prepared.

(*Paper No. 2823.*)

"The Estuary of the Tay."

By David Cunningham, M. Inst. C.E.

The estuary of the Tay extends from the bar up to the mouth of the River Earn, a distance of 24 nautical miles, above which the river contracts to a quarter of a mile in width, Fig. 1, Plate 6. From the upper end of the estuary, the width increases uniformly as far as 4 miles above the harbour of Dundee, where it is 2¾ nautical miles. Sandbanks extend, mainly on the north side, over many square miles in this section of the estuary, which dry 7 to 8 feet at low-water, the width of the navigable channel being only about ⅝ mile. There are also sandbanks within the main channel, composed of coarser and cleaner sands than the extensive flats to the north. These banks change little from decade to decade; and in this respect, the estuary of the Tay differs from that of the Mersey, where the course of the channel changes from year to year. At Dundee the estuary is 1¼ nautical mile in width; and at Broughty Ferry, 3 miles below Dundee, it is only ¾ mile across. Opposite Dundee a sandbank exists, 150 yards in width at low-water; but at Broughty Ferry there are no sandbanks, and the river is 10 fathoms deep at low-water. Seaward of Broughty Ferry the estuary widens abruptly, and the bottom consists largely of coarse sand full of water-worn granitic stones. A mass of this material, 11 feet below low-water level, near the Horse-Shoe Buoy, on the south side of the fairway, restricts the width of the deep navigable channel to 1,000 feet, and another similar shoal lies at a depth of 14 feet below low-water level, in the centre line of navigation near the Lady Buoy; but there is deeper water to the north. The bottom of the estuary between these buoys, on the north side, being formed of these materials between 9 and 12 feet below low-water, the currents in the navigable channel are more rapid. The channel deepens between the Lady Buoy and a point near the bar, a length of 4 miles, and widens to ¾ nautical mile; and the river 1 mile above the bar attains a depth of 50 feet at low-water. The minimum depth on the bar in the centre of the fairway is 21 feet, though a depth of only 19 feet is found not far

off; and at a distance of 600 yards beyond the bar the depth is 50 feet at low-water, Figs. 1, 2, and 3, Plate 6.

Tides.—Spring-tides flow up the river as far as 2 miles above Perth, or about 9 nautical miles above the mouth of the River Earn. Low-water of ordinary spring-tides is the Dundee harbour datum, and is the level of the sill of King William IV. dock at Dundee harbour, 7·58 feet below ordnance datum; and high-water of ordinary spring-tides at Dundee is 16½ feet above that level, Figs. 4 and 5. The highest recorded tide at Dundee harbour, on the 8th of February, 1868, at 2.20 P.M., with full moon, and the river at Perth in high flood, rose 19 feet 5 inches above the sill-level; and the following low-tide fell to 1 inch below it. Ordinary neap-tides rise to 12 feet, and fall to 4 feet above the sill, Fig. 6. The lowest high-water, on the 20th of March, 1884, was 9 feet 7 inches on the sill; and the low-water immediately following was 6 feet, giving a range of only 3 feet 7 inches. Thus the extreme range at Dundee varies between 19 feet 6 inches and 3 feet 7 inches; and extreme low-tides sometimes fall 1 foot 5 inches below low-water of ordinary spring-tides. The tide in entering the mouth of the estuary flows at first in two directions. The sea-water, usually of a clear bright-green colour, flows from the north across the Gaa Spit, Fig. 1; while the returning river-water, which is of a purplish-brown colour, flows back up the main channel. The first stream, therefore, pushes broadside on the other, forcing itself underneath it in a wedge-like manner. The mass of the sea-water gradually forces the north edge of the river-water southward, and the line of demarcation between the two remains for some time quite distinct. The sea-water also enters the estuary over the Abertay banks, and flows strongly through an opening above the lightship.

The presence of the flood-tide is perceived upon the north side of the estuary in several ways. First, the saltness of the water at spring-tides upon the north shore is between 10 and 25 per cent. greater than that upon the south shore, till the ebb-tide has fairly commenced. Secondly, the current of the flood-tide is so strong in the vicinity of Dundee as to give an inclination to the surface of the water, so that at half-flood the level is 2 to 3 inches higher than it is on the opposite side of the estuary. The flood-tide upon the north side also manifests its power—notwithstanding the retarding influence of the Fowler and Beacon Docks, near the entrance to the Camperdown Docks—in preventing the sand upon the north side, between the Tay Bridge and the harbour, from moving rapidly down the estuary, and therefore is salutary in

maintaining the approaches to the harbour and the pier of the Tay Ferry on the upper side of the harbour. This beneficial influence has become more marked since the Harbour Trustees completed the line of the harbour wall, to meet the shore-line to the eastwards, about ten years ago. Before this the flood-tide was deflected southwards by the bluff eastern termination of the harbour works. An inclination of the surface of the water, similar to that just mentioned, occurs on the ebb. These phenomena are due to the main flood-channel near Dundee, and the main ebb-channel near Newport, directing the volume of the water towards the north and south shores respectively.

The ebb-tide in approaching the entrance to the estuary bends to the north, and runs across the Gaa sands so long as these are covered, Fig. 1. The saltness of the surface-water at the lightship near low-water during heavy land-floods is sometimes as low as two-fifths of that of sea-water, while the mass of the water beneath is much more salt. Thus on the 30th of September, 1892, the specific gravity of the water at the lightship was 1·0105 on the surface, 1·0246 at a depth of 3 fathoms, and 1·0257 at the bottom, a depth of 7½ fathoms. There is generally a greater difference in salinity and temperature between the surface and bottom layers of water upon the flood than upon the ebb, the water being not quite so much intermingled vertically upon the flood- as upon the ebb-tide.

The results of seven observations, extending over thirteen hours each, made in 1885 and 1886 at various stations on the estuary and river, as to the rate of propagation of the tidal wave during spring-tides between different places in the estuary, are given in the following Table, together with Messrs. Stevenson's observations made at earlier dates.

Localities.	Distance.	Average Depth.		Rate of Propagation of Tidal Wave. 1885–6.		Rate of Propagation of Foot of Tidal Wave.[1]	
		High-Water.	Low-Water.	Foot.	Head.	1833.	1844.
	Miles.	Feet.	Feet.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.
Buddon Ness to Broughty Ferry	5·50	22	32	8·00	12·23		
Broughty Ferry to Dundee	3·25	25	36	21·00	10·00		
Dundee to Balmerino	4·75	11	25	21·00	19·95	17·81	17·81
Balmerino to Newburgh	8·39	5	19	4·64	16·39	4·87	4·87
Newburgh to Perth	8·56	3½	14½	4·40	28·75	3·42	5·13[2]

[1] Report of Messrs. Robert Stevenson & Sons, January 7, 1845.

[2] After improvements.

The low-water line in the estuary varies, for at spring-tides the inclination is toward the sea, Fig. 4; but during neap-tides the inclination is reversed, the level of the water at Balmerino being lower than that at Dundee, that at Dundee lower than that at Broughty Ferry, and that at Broughty Ferry lower than that at Buddon Ness. Thus, on the 17th of September, 1885, the levels of low-water at these points were respectively 13, 7, and 3 inches below that at Buddon Ness, Fig. 6. This phenomenon is due to the momentum of the ebbing waters remaining unchecked by the rising tidal wave, for a period generally twice as long as that which occurs during spring-tides. In the above case the raising of the levels at the upper stations was primarily due to the land-water, the river at Perth being then in flood and at almost double its usual height. In the absence of land-floods, the depressions in the levels of low-water should, therefore, be even greater than those mentioned. When the low-water line is thus depressed, the rapidity of the passage of the foot of the tidal wave up the estuary is greatly increased. For example, between Broughty Ferry and Balmerino, the foot of the wave attained a velocity of 96 miles per hour on the 13th of September, 1885; and the velocity may occasionally be even more. The velocity of the foot of the wave between Newburgh and Perth, mainly above the estuary, is lower during a land-flood because of the increased gradient. On the contrary, the passage of the head of the tidal wave between these points is somewhat accelerated during land-floods.

Quantity of Land-Water.—The River Tay receives a larger amount of land-water than any other river in Great Britain. The Author is indebted to the late Mr. John Peattie, engineer of the Perth waterworks, and to Mr. Alex. Davidson, his successor, for observations of the daily height of the river at Perth at low-water between 1882 and 1893, from which a diagram of the average, and of the maximum and minimum monthly heights of the land-water at Perth has been prepared, Fig. 7. The average height of low-water at Perth, when the effect of the tide in raising the water has been eliminated, has been found to be, for the twelve years from 1882 to 1893 inclusive, 4 feet ½ inch on the water-works gauge at the railway bridge. The lowest low-water known was 1 foot 7 inches on this gauge; and the highest high-water was 16 feet 10 inches, during the great flood of 1847. In 1811, however, the flow of the water was seriously obstructed by an exceptional amount of ice in the river, and the level rose to 19 feet 8 inches. The gradient of the water-line at high-water

and during heavy floods is about 1 in 2,000. The water-level at Perth during heavy land-floods may be raised about 30 inches by a spring-tide. On the other hand, during easterly gales the influence of the tide may be inappreciable. The gradient of the low-water line from the railway bridge to the harbour at Perth, varies according to the amount of water in the river, being flatter with a fuller channel. It is 1 in 1,150 at an average height. To obtain the average flow in the river at Perth, float observations have been made at different depths, from which the velocities were ascertained. The discharge of land-water throughout the year averages 400,000 cubic feet per minute, equivalent to an average rainfall of about 50 inches throughout the river-basin having an area of 1,823 square miles. Dr. Buchan, secretary of the Scottish Meteorological Society, estimates the average annual rainfall in Perthshire at 66 inches; and Mr. Gale, M. Inst. C.E., engineer of the Glasgow waterworks, estimates the rainfall absorbed or evaporated at 14 inches per annum, which leaves a rainfall of 52 inches flowing past Perth to the sea, or 4 per cent. more than the calculated flow; and it is probable, therefore, that this quantity may be under the actual discharge. The flow in the Earn, some little distance before it reaches the Tay, and at a normal level, was gauged at 36,000 cubic feet per minute; and the flow of the other streams which fall into the Tay between the River Earn and the sea, estimated at 20 inches of rainfall per annum after deducting 14 inches for evaporation and absorption, amounts to 16,000 cubic feet per minute. These give a total of 452,000 cubic feet per minute of land-water flowing, upon an average, throughout the year into the estuary.

A flood, however, rising at Perth to three or four times the average height, such as the floods of 1847, 1868, 1892, and 1894 will discharge five or six times the average amount of water into the estuary during a tide; while in dry weather, the discharge may decrease to one-third or one-fourth of the normal amount.

Tidal- and Land-Water.—The range between high- and low-water in the estuary may vary between 19½ feet and 3 feet 7 inches, and, therefore, the tidal volume may vary between about 22,000 million cubic feet and 4,600 million cubic feet, or between about 5 and 1. If, therefore, a high land-flood takes place simultaneously with a low neap-tide, nearly half as much land-water will enter the estuary during that tide as sea-water. Should such a land-flood occur during a high spring-tide, the ratio of land-water to sea-water entering the estuary during that tide will be about 1 to 10, namely about 1,600 million, and 16,000 million cubic feet

respectively. Under average conditions, however, the relation between the flow of land-water and that of sea-water is as 1 to 50, namely, about 280 million, and 14,000 million cubic feet respectively. Again, the relation between the summer flow of land-water and an average tide will be as 1 to 200, namely, about 70 million, and 14,200 million cubic feet respectively. The ratio of sea-water to land-water in the estuary is normally such that at the middle of its length—at Dundee—there is just as much fresh water as salt, and at the Pile lighthouse, ¼ mile below Tayport, the quantities of sea-water and land-water are, on the average, as 2 to 1. The ratio of the land-water to sea-water at Dundee usually fluctuates between one-fifth and four-fifths during a tide; but it will, of course, vary with the varying quantities entering the estuary.

Currents.—The changing ratio between the land-water and sea-water exercises an important influence upon the currents of the estuary. With a high land-flood and a low neap-tide there are exceptionally strong currents in the river and the upper parts of the estuary; but owing to the total quantity of the water being small the ebb-tide is feeble in the estuary generally. Extraordinary currents are occasioned when high land-floods and high tides occur simultaneously. When strong winds raise waves, and these waves act when the land-water and sea-water, and therefore the currents, are at their maximum, the greatest amount of silt and sand will be raised and carried away from the banks in the upper estuary. As these banks are so high that they can no longer receive deposits at or near low-water, they will receive them towards high-water only. The land-water which comes down the river in flood during neap-tides will meet a feeble flood-tide, and so, having an unusual quantity of materials in suspension, will deposit when the water rises sufficiently to cover the surfaces of the banks in the upper estuary. These surfaces are thus eroded and added to as storms and floods determine. The extent of such erosion is indicated by the larger quantity of materials found in suspension in the water of the estuary during such weather. Some indication of the bulk of fine silt carried in suspension in the water of the estuary is given by the amount of dredging necessary to maintain the West tidal harbour and the Craig harbour at Dundee, 5¾ acres in area, in a condition of efficiency. In these the dredging has varied from 10,000 tons per acre per annum to about half as much recently, so that the depth of accumulation varies between 50 and 27 inches per annum.

The Trustees of the Harbour of Dundee had their attention

directed in 1843 to certain encroachments which were being made by the proprietors of the adjoining land upon the sandbanks in the upper estuary. From a statement by Mr. James Leslie, the engineer to the Trustees, and a report by Mr. James Walker, it appeared that the area that would be enclosed by the dykes, which had been built out or were in course of construction in the estuary, assuming their ends to be connected together by an imaginary line, would be 3 square miles, equal to one-ninth of the whole estuary between the mouth of the Earn and Dundee. None of these dykes were more than ten years old, and they were being extended rapidly, so that when Mr. Walker reported [1] upon them in 1845, they formed, in his view, "traps or nets to catch and deposit the alluvial matter which is brought down the river, and is held in suspension while the water is in an agitated state." His conclusion as to the effect of these dykes upon the bar was, "that the reduction of the estuary by the proposed enclosures would be injurious to the harbour," and that this would be a practical injury, for "if the river-water" (during a land-flood) "were to be turned into an enclosed space of 1,800 acres" (similar to that encroached upon by the dykes), "it would require ten hours to raise it 8 feet in depth" (that is, to the level of high-water). Again: "The silting effect of the embankments upon a portion of the large space also that would be left between the outside dykes and the low-water channel, would, though gradual, be certain, and in the end considerable. I have already referred to it as arising from the contraction of the width, and consequent quieting of the surface, or 'laying' of the waves, to which, and not to the current, the depth is due." Seven sections were taken by Mr. Leslie across the estuary in 1843, but only three of these show the ground in the vicinity of the dykes complained of. The amount of silting which has taken place on the north side of the estuary, at each of these sections, has been different; but it averages 2 feet in depth for a distance of 1,500 feet, and in one case about 15 inches in depth nearly to the edge of the channel, 5,500 feet from the north shore. Such a complication of changes has taken place upon the surfaces of these banks during the past fifty years, that it is difficult to say to what extent silting may have prevailed over erosion. In some cases the channel has encroached upon the banks, in others the banks upon the channel; and on one section a gullet, shown at A, Fig. 1, ¼ mile in width, has been levelled up to the height of 20 feet. Upon the whole, the general level has been raised between 18 inches

[1] Report to the Trustees of the Harbour of Dundee, 21st January, 1845.

and 2 feet, so that between 300 million and 400 million cubic feet have been deposited; and this volume, equivalent to a forty-second part of the whole, has been abstracted from the tidal flow in the estuary. It is uncertain whether these changes are due to the presence of the above-mentioned dykes, or whether they may not be in some degree attributable to a general tendency towards deposition in that part of the estuary. Probably while this tendency prevails, the dykes may have materially contributed towards the changes which have occurred. In any case, the result has justified the anticipations which led Mr. Walker to recommend that the building of these dykes should be discontinued.

At the surface at high-water there is full six hours' flow of the land-water, which occupies space that would otherwise have been occupied by the sea-water. When, however, a land-flood occurs, the level of high-water in the estuary, and even of a high land-flood at Perth, is raised by the influence of the tide. The sea-water then increases the effect of the land-flood in the estuary. Upon such occasions, the high-water surface towards Perth is inclined upwards more than usual. Thus, while ordinarily the difference between the levels at Dundee and Perth railway bridge is between 21 and 24 inches, during high land-floods it is generally between 6 and 7 feet. The difference, however, during the great flood of 1847, amounted to 10¾ feet, high-water having been 14 feet 10 inches at Dundee, and 25 feet 7 inches at Perth railway bridge, above Dundee harbour datum. The comparatively low level at Dundee may probably be attributed to easterly gales having prevailed for some time before, whereby the water in the North Sea was driven into the Atlantic Ocean. When the ebb commences, the land-water operates fully upon the currents, and adds to their velocity; and the higher the land-water in the upper river, the greater will be the ebb currents throughout the estuary. The difference between the average level of the river at Perth, and the level of a high land-flood, may be taken as 9 or 10 feet; and upon a total length of 31 nautical miles, the increased elevation at Perth (with the augmented quantity of water due to such circumstances) will produce considerably increased ebb currents in the estuary; for as the ordinary difference between the water-surface at Perth and that of the sea at low-water is only 13 feet, this additional height will greatly increase the average gradient of the water-surface between Perth and the sea. On such occasions, low-water at Dundee is about 4 feet higher than usual, which shows the increased gradient which is realised towards low-water in the lower estuary.

From nine complete series of observations upon the level of the tides at various stations upon the estuary and river, it appears that the average inclination of the surface of the water during the latter part of the ebb-tide is one-half greater than it is upon any part of the flood-tide, the weaker currents at and towards slack water being eliminated. It is during the lower part of the ebb that its scouring effect upon the bottom must be greatest; it therefore follows that the movement of all materials in the estuary must be towards the sea. Observations show that, under ordinary conditions, the quantity of materials in the water at the Middle Bank opposite the harbour is somewhat less upon the flood than upon the ebb.

The chart of the estuary indicates that the large bank existing on its south side at Balmerino has been cut into by the current, and that the bank upon the north side of the estuary, to the west of the Tay Bridge, has also been cut into, Fig. 1. The main channel, therefore, now lies in a direction somewhat more across its general trend; and large quantities of sand have been washed away. There is first the mass which constituted the west end of the Balmerino Bank; secondly, that which formed the south edge of the northern bank; and thirdly, that which formed the Middle Bank, opposite the west end of Dundee. The aggregate amount of these masses could not have been less than 25,000,000 tons. Repeated surveys of the estuary from the sea, up to and beyond the harbour, prove that there has been no deposit of materials in the lower part of the estuary; and, consequently, this large quantity of material must have been carried by the ebb current downwards into the sea. While this has been proceeding since 1820, the harbour of Dundee, the Perth Railway, and the public esplanade to the west of the harbour, have been gradually constructed, whereby the width of the river, for a distance of 3 miles, has been reduced by about $\frac{1}{4}$ mile. These works must necessarily have intensified the currents; and the result of this, and the above-mentioned changes, has been that, whereas the sandbank in the middle of the river sixty years ago occupied a space of 140 acres, it gradually diminished till ten years ago it had become only a small shoal 4 feet below low-water. Since then, and during the past nine years, a long narrow sandbank of limited dimensions has formed from the banks above the Tay Bridge. The projection of a line of river-wall at Dundee has accordingly tended, in co-operation with the above-mentioned causes, to reduce the accumulations, and so produce a material improvement in the adjoining estuary.

The position of the outer portion of the Gaa shoal, upon the north side of the entrance to the estuary, has altered considerably during the past sixty years; and the sailing course has likewise been shifted. These changes show that the estuary has extended seawards, this extension having been accompanied by the removal of not less than 30,000,000 tons of sand.

At two points, then, there have been extensive changes in the bed of the estuary, with the removal of about 25,000,000 tons between Balmerino and Dundee, and about 30,000,000 tons of sand at the lower part of the estuary. Large quantities of sand and silt also are passing downwards, as shown by a bank which extended from Buckingham Point (1 mile above the harbour of Dundee) to the harbour in 1837, called the Ballast Bank, gradually coming downwards, so that about 500,000 tons were deposited in front of the harbour between 1837 and 1869, indicating a movement of about 15,000 tons per annum. Though this position is a comparatively sheltered one, the effect of the ebb-tide was felt persistently, causing a gradual diminution of the western bank and a corresponding increase of that further east. This accumulation, which seriously interfered with the approaches to the harbour, has, with 1,000,000 additional tons, been dredged since 1869 by the Harbour Trustees; and no deposit whatever—except of fine mud, near the entrance to the Camperdown Dock—has since taken place at this part. With an unobstructed flood-tide upon the north side, and the bulk of the ebb-tide upon the south side in the main channel, the sand necessarily occupies a zone between them. This sand forms the Middle Bank already mentioned, which is about 4 feet above low-water, and is 150 yards wide at that level. The water shoals at its lower end, so that the depth in the centre of the estuary, opposite the entrance to the deeper docks, is now only 6 feet below low-water. As the shores of the estuary, however, converge somewhat below this, it is supposed that the sandbank, which is a considerable obstruction to the crossing of the Tay Ferry-steamers from Dundee to Newport at low-water, will not extend much further eastwards in the immediate future. A considerable amount of the sand lying at the lower end of this bank constantly changes its position and extent, thereby showing that at a certain point the currents become too strong for the sand to lie, and that it is being continually drifted seawards. The sand composing the bank is finer than that of the shoal, the one having 2,000 particles, and the other 650 particles to the grain. The particles of sand composing the bank are, accordingly, too light to withstand the stronger currents over the shoal to the

eastwards, and they are carried downwards to the sea. It would be difficult to arrive at a reliable estimate of the quantity of sand and silt carried down the estuary to the sea. From the sand-banks and shoals about Dundee and Balmerino 25,000,000 tons have gone in a period of fifty years, so that the amount from this source alone is about half a million tons per annum. There is also the silt washed from the banks in the upper estuary, which escapes to sea, as well as that which comes down the river. The total quantity, therefore, may be about 1,000,000 tons annually. It is also difficult to estimate the amount of material which passes downwards into the estuary from the upper river. Although the river at Perth, during ordinary floods, is of a dark-brown or black colour, it contains only a small percentage of solid materials of any description, and a small fraction of what is found in the water of the estuary in stormy weather. Observations upon the water of the river at Perth during normal conditions show that the amount of solid material is small; and the bulk of the material coming down the river is due to high floods.[1]

During the flood of February, 1894, the embankments of the upper river were frequently broken through, and the fields at these points were often covered by large masses of gravel, the stones, 3, 4, and 5 inches in diameter, having been raised by the water up to the higher level of the fields. Near Dalguise, hundreds of tons of such gravel had thus accumulated; while on more distant fields, large quantities of coarse sand had been deposited. The sands of the estuary are similar to those to be found in the upper river. The chief characteristic of this flood was the rapidity with which the water rose in the rivers and lochs, the greater portion of the rise having taken place within twenty-four hours. The rise above the average level at Perth at low-water was nearly 10 feet, at Dunkeld it was about 13 feet, and at Pitlochrie about 15 feet; while in Lochs Tay and Tummel, it was 7 feet, and 9½ feet respectively. On the day preceding the flood, the rainfall at the head of Loch Katrine, 30 miles distant, was 3·9 inches; and in the preceding week the rainfall had been 10 inches, about one-ninth of the annual rainfall there.

---

[1] Samples of water taken from the river at Perth when 6 feet 9 inches high (an ordinary state) give $\frac{1}{10\,000}$ as the proportion of solid inorganic materials. This is equivalent to 730,000 tons per annum. Samples taken at 1 foot 9¾ inches (a very low level) give $\frac{1}{28,500}$ as the proportion of solid materials. These results may be considered corroborative of the statements in the text.

The banks in the estuary are composed of different grades of materials; and it has been observed that the fineness of the materials on the extensive banks in the upper estuary depends upon their height, and upon their distance from the main channel. An extensive shoal projects from the southern shore of the estuary, about half-way between Newport and Tayport, called the Newcome Spit, consisting of a mass of clean sand and shells, six times as coarse (320 to 2,000 particles per grain) as that of the Middle Bank, which is 2 miles higher up the estuary; and in consequence of its weight, the shoal has moved bodily downwards 300 to 400 yards during the last sixty years. As the northern edge of this spit extended so far north as to leave a width of channel of less than 500 yards available for vessels of large draught, the navigable channel forming a curve at the place, large vessels, in approaching the harbour, were sometimes apt to run aground upon the north shore. In 1887 the channel was widened about 500 feet, by scouring the northern edge of this spit with a screw propeller and dredging.

The Bar.—The depths upon the bar in the line of the sailing course have increased since 1833, the date of the first reliable survey, till the present time, as shown by sections of the bar from various recent surveys, Figs. 2 and 3. Between 1833 and 1885 there was a general increase of depth; and during the subsequent eight years the indications of continued improvement were still appreciable. Large quantities of sand have been removed from the estuary at and above Dundee, and in the lower part of the estuary; and there were also 840,000 cubic yards dredged from the channel between Newburgh and Perth during some years previously to 1844, as well as nearly twice that quantity dredged at Dundee. While the removal of the accumulations at and above Dundee has undoubtedly enlarged the channel, yet the deepening of the bar cannot well be attributed to such improvement. Neither can the removal of 840,000 cubic yards of materials from the bed of the river between Newburgh and Perth, where the width is only one-tenth that of the estuary, and where the distance from the sea is so great, have had any appreciable influence upon the flow of the tidal wave in the estuary. Nor can the dredging of 1,500,000 tons in front of Dundee Harbour have had such an influence. The change which has taken place in the lower part of the estuary, whereby the position of the bar has gone nearly a mile seaward, is one of more importance, in view of the alterations which have occurred in its depth.

The following Table of distances of the bar (the point where the

outer 3-fathom line crosses the centre of the fairway) from the Pile Lighthouse, shows the alterations which have taken place:—

Date of Chart.	Distance.	Diminution of Distance.	Increase of Distance.
Year.	Feet.	Feet.	Feet.
1704	41,420[1]		
1792	38,200[1]	3,220	
1833	41,850	..	3,650
1838	43,450	..	1,600
1844	42,860	590	
1855	42,900	..	40
1858	41,040	1,860	
1866	43,670	..	2,630
1876	45,140	..	1,470
1885	46,450	..	1,310
1894	46,570	..	120
		5,670	10,820
			5,670
Difference, being amount of movement of entrance seaward . .			5,150

This change in position signifies that the estuary has been lengthened by nearly a mile; and as the whole length is about 24 miles, approximately 4 per cent. more water passes over the bar than formerly. Accordingly, notwithstanding the large abstraction by deposition upon the banks of the upper estuary and by reclamation at Dundee, there has been an addition in the tidal capacity of the estuary, so that the scour upon the bar and adjoining sands has been augmented, and the depths thereby increased. The changes in depth at the entrance to the estuary are shown in the Table on p. 312.

The line chosen as a base for these data runs almost due east and west, nearly touching the earlier Gaa sands as they stretched out eastwards, but running across them as distributed southwards in 1833 and 1837, when the depths were 3 feet, 6 feet, and 7 feet, as compared with 3 fathoms at the earlier date.[2] The depth on the bar was least in 1792, 1833, and 1844, and greatest in 1846 and latterly. The survey of 1846, however, on account of the infrequency of the soundings, can scarcely be considered altogether reliable as to the minimum depth upon the bar. The condition of the entrance at present, as compared with its condition in 1846,

[1] These distances may be considered as only roughly approximate.
[2] This distribution of the sands southwards has also had the effect of altering the position of the bar further southwards in a corresponding degree.

exhibits a notable improvement in respect of its greater amplitude.

Of late the continuity of the sands on the south side of the entrance to the estuary has been broken, an opening, about $\frac{1}{2}$ mile wide and 5 feet deep, having taken place within the last few years, 1 mile above the position of the lightship, through which

Chart.	Gaa Sands run out.	Depth on Bar.	Minimum Depth on Line of Tayport Lights.	Minimum Depth extending South of Tayport Lights.
1686–1704. Adair	$2\frac{3}{4}$ miles	3 fathoms	3 fathoms	3 fathoms
1792. Murdo Downie . . .	$1\frac{1}{4}$ mile	$2\frac{1}{2}$,,		
1833. Commander Slater . .	$\frac{3}{4}$,,	16 feet	3–6 feet	6 feet[1]
1837. Robert Stevenson & Son	1 ,,	$2\frac{3}{4}$–3 fathoms	7 ,,	7 ,,
1844.	..	16 feet	12 ,,	10–12 feet
1846. R. Stevenson & Steedman	$\frac{9}{10}$,,	$3\frac{3}{4}$ fathoms	$2\frac{1}{4}$ fathoms	2 fathoms
1858. D. and T. Stevenson .	1 ,,	$2\frac{3}{4}$,,	$2\frac{3}{4}$,,	$2\frac{1}{4}$,,
1862. D. and T. Stevenson .	1 ,,	$2\frac{3}{4}$,,	$2\frac{3}{4}$,,	$2\frac{1}{4}$,,
1863. Special survey . . .	6 cables			
1863. Admiralty	$\frac{3}{4}$ mile	17 feet	17 feet	14 feet
1866. ,, ...	1 ,,	17 ,,	15 ,,	15 ,,
1876. ,, ...	$\frac{4}{5}$,,	17 ,,	12 ,,	12 ,,
1885. ,, ...	$\frac{3}{5}$,,	18 ,,	13 ,,	14 ,,
1893. ,, ...	$6\frac{1}{2}$ cables	19·21 ,,	15 ,,	14 ,,

the flood-tide enters with great force. It may be that this change, especially if it increases, will, by diminishing the effect of the flow and ebb of the tidal waters over them, affect the extent of the sands at and near the entrance.

The Author is of opinion that the improvements at the entrance to the estuary must be attributed to the land-floods. There was the heaviest known land-flood in 1847, when high-water rose 16 feet $2\frac{1}{2}$ inches, or 12 feet $2\frac{1}{2}$ inches above the average low-water level at Perth; and in 1868, another land-flood occurred, when the height was nearly as great. In January and February, 1892, and in February, 1894, the levels attained were within 12 and 14 inches respectively of the flood of 1847; and there have been other such floods. The currents upon the ebb throughout the whole estuary are immensely intensified by such floods; and their effects upon the bottom are increased, owing to the additional volume and height of the water. The gradient of the water between Perth and Dundee towards the latter part of the ebb—when the currents are strongest—is then fully one-half more than

[1] Depth of 25 to 34 feet where outer end of Gaa Spit existed in 1690 according to Adair's chart.

it is ordinarily. The Author noticed the ebb current at Dundee, during the land-flood of February, 1894, running at between 5 knots and 6 knots per hour, being half as fast again as it is during high spring-tides when unaccompanied by land-floods. Bearing in mind that such floods exert their influence over several tides, it can easily be imagined that it is mainly to such comparatively infrequent phenomena that the great changes in the position of the shifting sands in the estuary are due. Ordinary weather and currents in the estuary cause little alteration of deposits. It is only when the rain falls heavily, the snow melts rapidly, and the prevalent south-west wind blows strongly upon the lochs, that the land-floods come down in exceptional volume; and it is when these are combined with high spring-tides that changes are produced, which never take place through the operation merely of normal conditions. But when the land-floods have carried the bar and its flanking sands seawards to their fullest extent, the action of the waves, it may be presumed, will become more powerful upon a frontier thus extended; and so it may be expected that side channels will develop, whereby the scouring force of the powerful ebb currents will be materially reduced before they reach the bar. Thus periods of improvement and of deterioration will probably alternate; but as the accumulations continue in the estuary without cessation, there must be a secular contraction of the amount of tidal flow, and this cannot but be accompanied with its concomitant, a slow but changeful diminution of depths.

The Paper is illustrated by fifteen tracings, from some of which Plate 6 has been prepared.

(*Paper No. 2825.*)

"The Pecos Viaduct, Texas, U.S.A."

By Henry Wilson Hodge, Assoc. M. Inst. C.E.

The viaduct which forms the subject of this Paper is situated at a point about 220 miles west of San Antonio, between Schumla and Helmet, in the State of Texas, on an extension of the Galveston, Harrisburg and San Antonio Railway, which it carries over the Pecos River, a tributary of the Rio Grande, at a height of about 320 feet above low-water level. The railway referred to is one of the original lines acquired by the Southern Pacific Railway Company to form part of the main trans-continental route between San Francisco and New Orleans. The Pecos River runs in a deep gorge and formed a barrier to the construction of a direct line between Schumla and Helmet, so that hitherto that portion had followed the Rio Grande and crossed the Pecos River at their confluence just above high-water level. The actual distance between Schumla and Helmet has been reduced from 27·5 to 13·3 miles, while the extreme curves and heavy gradients have been avoided. It crosses the Pecos cañon by a single-track steel viaduct, 2,180 feet long and 321 feet high, now to be described. The profile of the cañon slopes gradually from both sides for a considerable distance, and then drops almost precipitously to the level of the river, Fig. 1, Plate 7, which is about 100 feet wide and 8 feet deep at low water, but in times of freshets it attains a width of about 500 feet and a depth of 55 feet.

Fig. 1 shows the general design of the viaduct, which consists of plate-girder spans, thirty-two of 35 feet, two of 35 feet 3 inches, and one of 45 feet; eight 65-foot riveted lattice-girder spans, two pin-connected cantilever spans of 172 feet 6 inches, and one 80-foot suspended span. The total length of the viaduct, between the back-walls, is 2,180 feet 6 inches. The smallest width of the main opening which could safely be used to pass the drift in times of freshets is 185 feet.

Masonry.—The masonry was commenced on the 28th February, 1891, and, as the entire cañon has been eroded from the rock, there

was no difficulty in obtaining perfect foundations for all the piers, as, except in the case of those in the bottom of the cañon (bents Nos. 11 to 17 inclusive), it was only necessary to remove a few inches of the weathered surface to reach the natural rock, a compact white limestone. It was necessary to remove the silt and boulders which covered the rock, in some places to a depth of 40 feet, for the river-piers, which were built to a height of 5 feet above high-water level and are 7 feet square at the copings, with a batter on each face of ½-inch in a foot. The highest pier measures about 80 feet from the bottom of the foundation to the top of the coping. The piers were built of limestone quarried on the site, and are capped with a coping of syenite granite 20 inches thick and 8 feet square in two pieces 8 feet long and 4 feet wide. All are turned diagonally to the direction of the current to diminish their resistance to it. The tower anchorages in each of the piers consists of four rods 2 inches in diameter and 20 feet long, connected at their lower ends to large anchorage plates, all of which were built in with the masonry. The weight of the masonry above these anchorage-plates is sufficient to resist two and a half times the maximum resultant upward force of the wind against the train and the structure. The small piers forming pedestals for the towers were constructed by removing the surface-rock and laying a few courses of masonry, capped with a coping-stone 3 feet square, to receive the shoe of the tower. There are two anchor-rods in these pedestals, 1⅞ inch in diameter and of varying lengths, passing through them into holes in the solid rock, in which they are set with Portland cement.

The masonry, amounting in all to 3,270 cubic yards, was completed on the 21st November, 1891, having been 229 working days in construction. The work was seriously delayed by sickness among the men due to the extreme heat, and by the great difficulty experienced in getting the sand, cement, and other materials into the cañon.

Method of Erection.—The great height of the structure and the inaccessibility of the bottom of the cañon for the delivery of material rendered it necessary to do all erection from the level of the line by means of an overhanging traveller, and all parts of the structure were designed with this in view. This traveller, shown in Figs. 2, Plate 7, was designed to lift a weight of 9 tons, so that under the stresses from such load, in addition to its own weight and that of all blocks, falls and other rigging, the iron rods of the structure were not subjected to a greater stress than 12,500 lbs. per square inch, nor the timber compression-members to more than

1,500 lbs. $- 18 \frac{l}{d}$ per square inch, where l is the length of the members and d is the width of its least side in feet. The traveller was 188 feet long and had an overhang of 124 feet 6 inches.

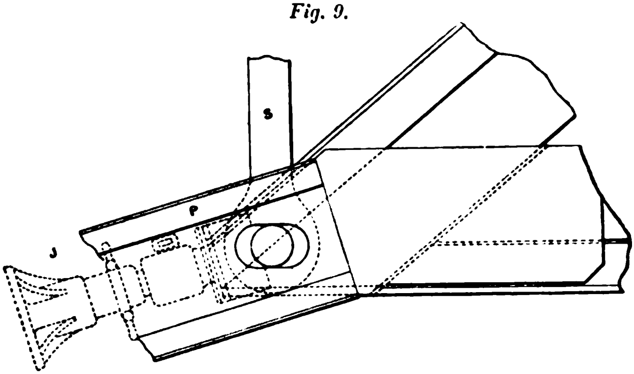
The work of building the traveller was commenced on the 5th October, 1891, and was completed on the 3rd November, thus occupying twenty-four working days. The entire traveller complete with all rigging and with the two 10-HP. boilers, the two four-spool winding-engines, and the counter-balancing weight, weighed 116 tons. This weight was so distributed that it was evenly balanced about the forward wheels of the traveller, so that all weight came upon those wheels when the traveller moved. When lifting a weight the traveller was clamped to the girders over which it was standing by the anchors shown at B, Figs. 2, Plate 7. It will be seen that the traveller ran on four rails, 10 feet and 18 feet from centre to centre, and spanned the temporary track laid upon the structure for the delivery of material. The winding-engines and boilers were placed on a platform sufficiently high to allow a hand-car loaded with material to pass beneath it. The material was brought out on the structure by this hand-car and was then picked up by the winch on the trolley-car A, Figs. 2, and carried forward and lowered into the required position. The trolley-car could not run to the end of the overhang as it was there necessary to insert lateral bracing, but when material had to be placed beyond the reach of the trolley it was made fast to the fall C and passed from fall to fall along the overhang till over the position required and then lowered. This lowering for the extreme height required about eight minutes.

The erection was begun at the east end of the viaduct on the 3rd November, 1891. The first tower, together with the girders over it, were erected from the embankment, and when these were completed the girders of the span between the tower and the embankment were separately lifted into place and the bracing between them inserted. The traveller was then hauled forward by means of its own winding-engines till the forward wheels rested over the outside bent of this tower, from which position the second tower and span were similarly placed. This manner of erection was followed throughout, except for the anchor arm of the cantilever, in which case the trusses were too heavy and too large to be put in place in one piece. The main tower (No. 13–14) was here erected in the usual manner, and then, using bent No. 14 as an anchorage, the anchor arm was erected piece by piece from bent No. 13 towards bent No. 12 as a cantilever; a

temporary tie-rod being put in the truss panel nearest bent No. 14. When the anchor arm was thus connected to bent No. 12 the traveller was run forward till over the main tower, and from this position the lever arm and half the suspended span were erected.

The centre of the suspended span was reached on the 30th December, or in forty-nine working days. The traveller was then taken to pieces and carried round to the west end of the structure where it was set up again, and on the 8th January, 1892, the erection from this end commenced as from the east end. The suspended span was again reached on the 21st February, or in thirty-seven working days. On the two portions meeting at the centre the work was found to have been very accurately laid out and constructed, as, by a slight adjustment, by means of four

Fig. 9.



20-ton hydraulic jacks and the erection loops as shown in *Fig. 9*, the two ends were brought exactly together and riveted up, thus completing the structure.

The entire erection required 118 working days, or, deducting the time occupied in building and moving the traveller, 86 working days, giving an average of 41,970 lbs. of ironwork erected daily. The number of men employed for this work averaged sixty, and at no time exceeded seventy-nine. Only one accident occurred during the erection of the work, a man being killed by falling from the low portion of the viaduct, about 30 feet, to the ground.

Towers.—Figs. 3, Plate 7, show the details of tower No. 11–12. All the towers were built similarly to this one except towers Nos. 13–14 and 15–16, in which cases, on account of the large load carried from the cantilevers, the zee-bar legs were not of sufficient area of section, so that all the legs of these two towers were built of two

plates 24 inches wide, and four angles 4 inches by 4 inches. The batter of the column is in each case 1 in 6. The towers are all divided into stories of 32 feet 8 inches, except the top story, and any variation from this height was made in the lowest or two lowest stories; thus making the upper portions of all the towers alike and reducing the office and template work to a minimum. The top transverse story was subdivided as shown in Figs. 3, to obtain a better inclination for the upper transverse rods, and the lowest transverse rods were run through two stories with secondary transverse struts from their point of intersection to the intermediate longitudinal panel point, thus avoiding the very flat inclination and extreme length which these rods would otherwise have had. In addition to the vertical transverse and longitudinal bracing, each tower is braced horizontally at A, B and C, as shown in Figs. 3,

Figs. 10.

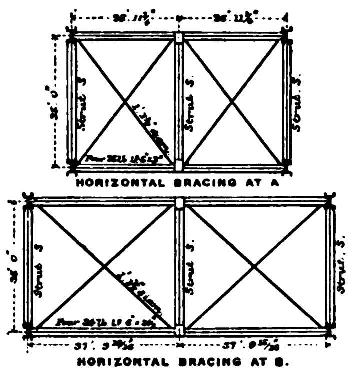


Plate 7, and *Figs. 10,* to prevent any distortion from unequal wind-pressure on the two bents. All joints throughout the towers are riveted, except the connections of the rods which are made with clevises as shown in the Figs. The longitudinal bracing rods and struts were designed to carry one-fifth of the maximum moving load to be borne by the tower, it being assumed that such load could slide on the application of the brakes, and one-fifth being taken as the coefficient of friction for wheels sliding on rails. The central leg in the large towers is inserted to stiffen the long transverse struts, and of course carries no load other than the weight of such struts and bracing.

Tower Plate-Girder Spans.—The length of the tower plate-girder spans, shown in Figs. 4, was set at 35 feet, as a greater length entailed too large a weight for the longitudinal bracing of the

towers. These spans were made of the full depth at the ends and rested directly on the tops of the columns.

Lattice-Girders.—The 65-foot lattice-girder intermediate span was taken as giving the longest and heaviest girder that could be economically worked by the traveller, though a somewhat longer span near the centre would have decreased the weight of the structure. Figs. 5 show these intermediate spans in which the ends were made 4 feet deep to match the depth of the end of the tower-spans. These spans are also supported directly on the tops of the bents. It will be noticed in this girder that long panels were taken for the triangulation, and secondary verticals were used to support the top chord against bending, this arrangement being found more economical than a perfect triangular system with shorter panels. Both the 35-foot and 65-foot spans have lateral and transverse bracing of angle-bars riveted in place as shown in the Figs.

Cantilevers.—The cantilever spans, Figs. 6, are pin-connected throughout, but have riveted lateral and transverse bracing. It was found that the stresses in this portion of the structure were so large that the number of rivets required at the joints made the connections excessively heavy, so that pin-connections became more economical. The jacks temporarily used for the adjustment and connection of the suspended span are shown at J in *Fig. 9*, but these were removed after erection.

Suspended Span.—The 80-foot suspended span for the central opening between the cantilevers, Figs. 7, is similar in design to the 65-foot spans.

Floor.—Figs. 8 show the arrangement of the timber flooring, &c., which contains about 122 feet, board measure, per lineal foot. The plank sidewalks and railings were provided solely for the use of employés of the road, as no foot-passenger traffic is allowed on the structure.

Quality of Steel.—The superstructure of the viaduct is entirely of mild steel, the tensile strength of that part of it used in tension being 62,500 lbs. per square inch, and of that to be used in compression 68,000 lbs. per square inch. From one ingot of each heat two round sample bars not less than $\frac{3}{4}$ inch in diameter, and having a length of not less than twelve diameters between the jaws of testing-machine, were furnished and tested by the manufacturer. Both these test-bars have a tensile strength within 4,000 lbs. per square inch of the above value, an elastic limit of not less than one-half of the tensile strength of the test-bar, a percentage of elongation not less than 1,200,000 divided by the tensile strength in lbs. per square inch, and a percentage

reduction of area of not less than 2,400,000 divided by the tensile strength in lbs. per square inch.

The elongation was measured after breaking on an original length of ten diameters of the test-piece, in which length the curve of reduction from stretch on both sides of the point of fracture must occur. The rivet-steel had a tensile strength of 60,000 lbs. per square inch, and was capable of bending double, flat, without signs of fracture on the convex surface of the bend.

Loads carried.—The structure is designed to carry, in addition to its own weight and that of the ties, guards, rails, &c., amounting to 400 lbs. per lineal foot, the following train-loads considered as moving: for the spans of 80 feet and under, 5,000 lbs. per lineal foot, in addition to a load of 30,000 lbs. concentrated at any point; and for spans exceeding 80 feet, 4,000 lbs. per lineal foot, in addition to a load of 30,000 lbs. concentrated at any point. The former load was used in the computation of all parts of the structure except the towers, which were computed for the latter loads; and this was also used to obtain the stresses in the anchor arms of the cantilevers due to the load on the suspended span and lever arms. These loads on the short spans give unusually heavy stresses, and it was the purpose of the Southern Pacific Company to thus prepare the structure for future increase in weight of rolling load.

Wind-Pressure.—In addition to these vertical loads, and simultaneously with them, the structure was constructed to resist a horizontal wind-pressure of 30 lbs. per square foot of its exposed surface and floor, in addition to a moving wind-load of 300 lbs. per lineal foot (10 square feet of train-surface) concentrated 9 feet above the level of the rail; or to withstand a horizontal pressure of 50 lbs. per square foot of the exposed surface of the structure and floor. This latter condition of wind-loading was only used in computing the upward stresses in the windward legs of the towers.

Unit-Stresses.—No part of the structure under maximum stresses from these loads is subjected to greater stress than the following:—

	Lbs. per Square Inch.
Tension in long verticals and counter web-members	9,600
„ main web-members and lower chords (eye-bars)	12,000
„ main web-members and lower chords (plates or shapes)	9,600
„ lateral bracing	15,000
Shearing across fibres	9,000
Extreme fibre-stress in pins from bending	18,000
Compression (lengths less than forty radii of gyration)	9,600
Bearing-pressure on surface of pins	14,400

For compression-members exceeding forty radii of gyration in length for square ends—

$$p = \frac{9{,}600 \text{ lbs.}}{1 + \frac{l^2}{35{,}000\, r^2}};$$

for pin ends
$$p = \frac{9{,}600 \text{ lbs.}}{1 + \frac{l^2}{17{,}000\, r^2}}$$

for unsupported compression-flanges of plate-girders—

$$p = \frac{9{,}600 \text{ lbs.}}{1 + \frac{l^2}{5{,}000\, b^2}};$$

where p is the allowed pressure per square inch, and l the length of the member, b the width of the flange, and r the least radius of gyration in inches.

In deriving the sections of the members the wind-stresses are not combined with the moving and dead stresses unless they are as great as one-third of them. The allowed unit stresses for the sum of the three stresses are one-third greater than those given above. The structure was also designed to carry during erection the traveller, weighing 116 tons, which was assumed to be concentrated at one point, being balanced about its forward wheels as already described. By these additional stresses the unit stresses were increased 50 per cent., as the loads were only once applied, and then in a gradual manner. The entire structure was carefully computed under the above conditions, including each detail and connection.

It will be noticed that the diagonal rods over the main towers are so placed as to carry no shear from the lever to the anchor-arms of the cantilevers, so that all stresses are perfectly determinate, and these rods act purely as secondary members to support the long upper chord-panels above the towers. The timber ties carrying the rails are laid directly on the upper chords of the girders and cantilevers, these portions of the structure having been proportioned to resist the combined bending and direct stresses.

Expansion and Contraction.—The expansion and contraction of the structure is provided for as follows:—The 35-foot tower span will expand with the tower itself, and the expansion of it, as well as that of the adjoining 65-foot span, is allowed for by making the holes in the 65-foot span, through which it is bolted to the towers, of oblong shape to allow sufficient motion in a longitudinal

direction only. The suspended span in the main opening is hung from above by bars S, Figs. 6, Plate 7, and *Figs. 9*, which swing round the upper pin; and the lower strut P and the upper chord B have oblong holes at one end to allow for the expansion of the suspended span and lever arms. The anchor-arm is connected to the anchor bent by a swinging link, Figs. 6, Plate 7, to allow for the expansion of the anchor-arm. The holes in the shoes of all columns are made ¾ inch larger in diameter than the anchor-bolts passing through them, thus allowing for the expansion of the longitudinal and transverse struts of the towers.

Weight.—The total weight of the structure is as follows:—

			Lbs.
Thirty-four plate-girder spans	35	feet long	495,550
One „ span	45	„	24,810
Eight lattice-girder spans	65	„	354,120
One „ span	80	„	57,870
Two cantilevers	172½	„	478,400
Floor-bolts and railings			51,620
Total weight of superstructure			1,462,370
„ „ towers and anchor-bolts			2,147,190
Total weight of the structure			3,609,560

i.e., 1,611 tons 8 cwt. 22 lbs.

Cost.—The total cost of the structure was as follows:—

	$
Masonry	42,505 (*i.e.*, £2 14*s.* per cubic yard).
Steel structure delivered at site	160,000 (*i.e.*, £20 10*s.* per English ton).
Erection, including cost of traveller	30,500 (*i.e.*, £3 18*s.* per ton).
Wooden flooring	5,325 (*i.e.*, £4 3*s.* per thousand feet, board measure).

The bridge was designed and manufactured by the Phœnix Bridge Company, of Philadelphia, Pa. No final tests of the structure were made, but it is found to carry the heavy traffic imposed on it in the most satisfactory manner, and no appreciable vibration is noticed either from passing trains or from the wind.

The Paper is accompanied by nine tracings and two photographs, from which Plate 7 and the *Figs.* in the text have been prepared.

(*Students' Paper No. 349.*)

(*Abstract.*)

"Some Experiments on the Heat Losses to the Cylinder-Walls of a Steam-Engine."[1]

By SAMUEL HENRY BARRACLOUGH, B.E., Stud. Inst. C.E., and LIONEL S. MARKS, B.Sc.

THE action of the cylinder-walls in modifying the economy of the steam-engine has been the subject of many investigations. Since its theoretical treatment by Hirsch and Cotterill, and the experimental work of Donkin and others, the nature of this action is known with fair accuracy; and its magnitude is also known, in a general way, for several types of engines, and under many different conditions of working, as a result of the labours of numerous investigators, notably those of Willans, from the time of Clark and Hirn. It is not known, however, how the type and dimensions of an engine, and variation in the conditions under which it is working, affect the heat losses to the walls; and many formulas have been proposed by different authorities to express the relation between the working conditions and the heat losses in the steam-engine, but none give results agreeing with the great mass of available experimental results, nor do the formulas generally agree with one another. In all the proposed formulas it is assumed that the variation in the heat loss corresponding to a variation in any one of the working conditions (pressure, speed, &c.), is proportional to some constant function of that quantity. There is, however, good reason to suppose that the law of variation of cylinder condensation, with change of one working condition, depends upon the other working conditions, and changes with them. If this is so, the proposed formulas are only applicable under the special conditions of the experiments from which they were deduced. Thus, one authority finds cylinder condensation to be proportional to the square root of the speed of the engine,

---

[1] This Paper was read and discussed at a Students' Meeting on the 14th of December, 1894.

another to the two-thirds power, and yet another to the first power of the speed. These opinions are probably all true for the particular conditions as to pressure, ratio of expansion, &c.

The present experiments were made to determine the effect of variations in the initial steam-pressure on the law connecting cylinder condensation with speed. Conversely they also showed the effect of change of speed on the law connecting cylinder condensation and initial pressure. Complete tests on the engine were made at four pressures, viz., 120, 100, 80, and 60 lbs. per square inch absolute, and at speeds of 85, 70, 55, 40, and 25 revolutions per minute; in all, twenty tests. The ratio of expansion and the back pressure were maintained constant throughout. The tests were carried out on the high-pressure cylinder of the horizontal triple-expansion surface-condensing Corliss engine at Cornell University, United States. This engine is so constructed that the high-pressure cylinder can be run as a simple engine. Its chief dimensions are:—

Diameter of cylinder	9 inches.
Length of stroke	36 ,,
Diameter of piston-rod . . .	$2\frac{5}{16}$,,
Clearance volume, head end . .	7·74 per cent. of piston displacement.
,, ,, crank ,, . .	7·45 ,, ,, ,,
Total clearance surface . . .	5·9 square feet.

The cylinder is provided with a jacket, but in these experiments no steam was admitted to it, and no leakage into it occurred. The piston and valves were tested before making the trials, and were found to be steam-tight. The exhaust-pipe leading to the first receiver was removed so that any leakage in that direction might be detected, and to ensure that all the exhaust steam went to the condenser. The power was absorbed by an hydraulic Prony brake. This consists chiefly of a copper tube of elliptic section encircling the brake-wheel and pressed against the rim by the pressure of water within the tube, tending to give it a circular section. It can be readily regulated by adjusting the water-supply valve. The brake was continuously lubricated, and this kept the load very uniform. The steam came from a 250-HP. Babcock-Wilcox boiler, situated about 20 feet from the engine. A separator in the steam-pipe between the boiler and the engine kept the entering steam practically dry, but the actual amount of moisture present was measured just before the steam entered the engine by a Carpenter throttling calorimeter. This is an instrument in which the moisture in the steam is measured by the

superheating which takes place when the steam is permitted to expand to a known pressure. The steam was tested for moisture continuously, the sample being taken through a ½-inch pipe screwed into the vertical steam-pipe and perforated with numerous holes ⅛-inch diameter. A new pair of Crosby indicators were used for taking diagrams, and were carefully calibrated under steam-pressure. Two sets of springs were used on account of the wide range of steam-pressures. The constants of calibration found for these springs were—

Spring	60 lbs.	Head end	0·979
„	60 „	Crank „	0·992
„	40 „	Head „	0·985
„	40 „	Crank „	0·968

The indicator pipes were very short; the cords also were short and direct. The motion of the indicator was good, and was obtained from a curved bar sliding on a pin through the centre of the cross-head. The steam was condensed in a surface-condenser and was conveyed thence to two barrels. The condenser was tested for leakage by opening a drain-cock at the bottom and keeping the circulating water under considerable pressure. During a prolonged test not the slightest leakage was observed. The circulating water was passed through a calibrated Worthington meter, and its volume thus determined, and the condensed steam was weighed in barrels placed on scales.

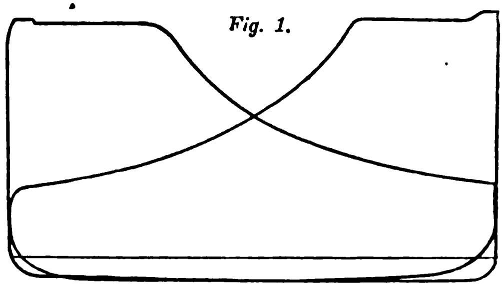
The desired variation in speed was obtained by using different governor pulleys, and by pressing upward with a long spiral spring on the sliding guide of the governor supporting the balls. By these methods each desired speed could be obtained and maintained constant. The cut-off, viz., 2¾ expansion, was kept constant throughout all the tests by varying the brake load.

The duration of each experiment was one hour, which, with the accurate means of measuring all the quantities involved, and the uniformity of conditions, was judged to be sufficient. Complete observations were taken at ten-minute intervals. Before making any observations the engine was allowed to acquire its normal working conditions.

The results arrived at are detailed in the Appendix. The tests are there referred to by the letters A to T; those with an asterisk are repetitions in which the desired conditions were not exactly attained on the first trial. The figures given are averages of all the observations during each trial. The measurements in columns 13–21 are taken from the indicator-cards, of which a

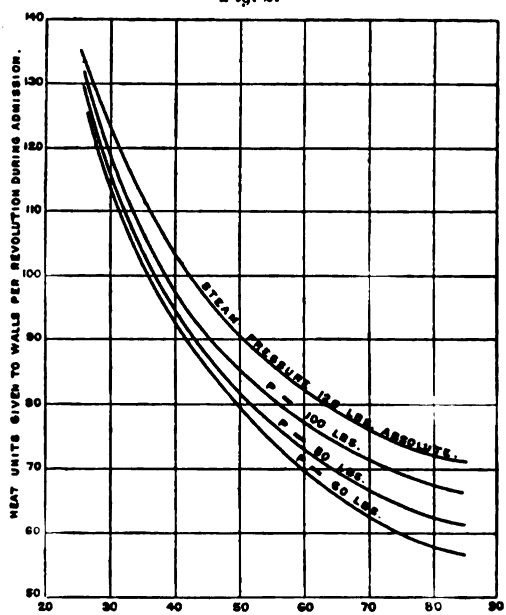
typical example is given in *Fig. 1*, and are all corrected for errors of springs, &c. The column headed "Total weight of fresh steam present at cut-off," pp. 233 and 234, gives the difference between

Fig. 1.



the total amount of steam shown by the indicator to be present at cut-off, and that remaining over from the previous revolution at the beginning of admission. The figures in the Table showing the number of heat-units given to the cylinder-walls per revolu-

Fig. 2.



tion during admission are the products of the weight of the steam condensed and its latent heat of evaporation.

The results are plotted in the manner shown in the example,

Fig. 2, the heat loss to the cylinder-walls being co-ordinated with the speed in four curves, for the four pressures respectively. Each curve is represented by the equation, $HN^x = \text{constant}$, where x decreases as the initial pressure increases, and ranges in these experiments between 0·49 and 0·68. It thus appears that the law connecting cylinder condensation and speed is a function of the initial pressure. The range of values of the exponent N (the number of revolutions) covers the values $\frac{1}{2}$ and $\frac{2}{3}$ given in some of the proposed formulas referred to already: other investigations with lower initial pressures than those attempted here give values of the exponent equal to and exceeding unity.

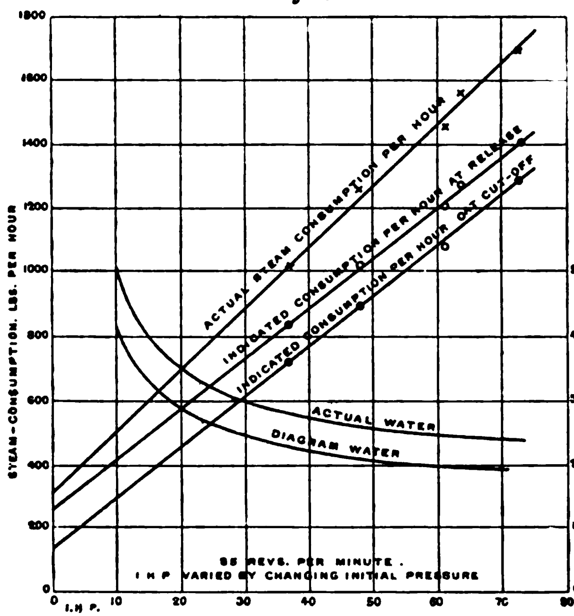
In another diagram five lines were drawn co-ordinating initial pressure with the heat loss to the walls per revolution, each line being for one speed. These lines were found to be straight lines of varying inclination, the latter being roughly proportional to the speed. They showed that the variation of cylinder condensation with initial pressure is greater the higher the speed, and that at low speeds cylinder condensation is almost independent of the initial pressure.

The results have also been plotted in the manner adopted by Willans, a typical example being given in *Fig. 3*. The co-ordinates are I.HP. and steam consumption in lbs. per hour. Three curves are drawn, representing "actual consumption of dry steam per hour," "indicated consumption at cut-off per hour," and "indicated consumption at release per hour;" also two other lines giving "lbs. per I.HP. per hour" and "lbs. per I.HP. per hour at cut-off from the indicator-diagram." Nine sets of curves were plotted, each of the first five being for a constant speed, the I.HP. being varied by change of initial pressure. In all of them the lines showing the consumption of water are approximately hyperbolas; the other three lines are straight. The curves therefore accord with Willans' law, which may be enunciated thus:—"When the power of an engine is varied by altering the boiler-pressure—the revolutions being constant—the total quantity of dry steam used per hour can be represented by a fixed multiple of the I.HP. plus a constant." The vertical ordinates between the lines of "actual consumption per hour" and "indicated consumption at cut-off per hour" give evidently the condensation per hour during admission; and since both lines are straight, the cylinder condensation, in an engine running at constant speed, can be represented by a fixed multiple of the I.HP. plus a constant, when the power is varied by altering the boiler-pressure. The ordinates between the lines

of "indicated steam consumption at cut-off" and "indicated consumption at release per hour" give the amounts of condensation or evaporation, or rather the algebraic sum of these during the period of expansion. In the diagrams, as shown in the example, *Fig. 3*, these two lines are parallel, and therefore the re-evaporation between cut-off and release is constant at each speed, that is, it is independent of the I.HP. and therefore of the initial pressure.

Each of the remaining four sets of curves is for one constant initial pressure, the I.HP. being varied by change of speed. The

Fig. 3.



same form of law is found to hold good; the lines showing the consumption of water are hyperbolas and the other three straight. It therefore appears that Willans' law can be extended to cover this case—an extension which is supported by an examination of Willans' trials and other experimental results.

The extended law may therefore be enunciated as follows:—
"When the power of an engine is varied, either by altering the initial pressure—the revolutions being constant—or by altering the speed—the initial pressure being constant—the total quantity of water used per hour can be represented by a fixed

multiple of the I.HP. plus a constant." In these last curves the line of "indicated consumption at cut-off" passes through the zero of ordinates—a result to be expected, as the speed of the engine is then zero. The point at which the line of "actual steam consumption" cuts the axis of ordinates gives the heat loss per hour due to external radiation from the cylinder. The re-evaporation from cut-off to release increases slightly with the I.HP. and, therefore, also with the speed.

The Paper is accompanied by numerous diagrams and a set of indicator-cards, from which the *Figs.* in the text have been prepared.

[Appendix.

APPEN

Reference Letter.	Intended Abs. Steam-Pressure. / Revs. per Min.	Revolutions of Engine per Minute.	Steam-Pressure above Atmosphere in Steam-Chest—Lbs. per Sq. In.	Condenser Vacuum—Inches of Mercury.	Temperatures, Degrees Fahrenheit. Engine-Room.	Condensed Steam.	Circulation Water—in.	Discharge Water—out.	Quality of entering Steam.	Steam Condensed in Surface-Condenser per Hour—Lbs.	Injection Water per Hour—Cubic Feet.	Mean Admission Steam-Pressures—Lbs. per Square Inch.
A	120/85	85·02	106·4	22·9	76	110·4	34·0	81·7	0·986	1720·0	567·5	117·0
B	120/70	67·00	106·6	22·4	76	108·4	34·0	84·4	0·988	1457·3	455·0	118·1
C	120/55	55·02	106·6	22·8	77	102·6	39·0	79·4	0·992	1242·5	488·0	119·4
D	120/40	40·62	108·2	23·8	77	81·4	37·0	62·8	0·985	961·0	584·0	120·7
E	120/25	26·58	106·8	23·6	77	78·7	36·5	58·8	0·986	699·3	490·2	120·0
F	100/85	84·87	87·1	23·1	77	96·9	37·1	72·6	0·982	1601·8	684·0	99·5
F*	100/85	83·85	89·1	22·6	74	117·3	34·0	91·3	0·987	1583·3	434·5	100·4
G	100/70	66·30	89·9	23·5	77	98·4	36·5	71·5	0·983	1302·8	586·5	100·7
G*	100/70	69·35	88·7	22·7	74	108·0	34·0	84·1	0·988	1328·0	417·0	100·6
H	100/55	54·90	89·9	23·5	78	89·2	36·5	64·9	0·981	1087·3	609·0	102·5
I	100/40	39·27	89·6	23·9	78	79·0	36·5	57·8	0·979	840·3	609·0	102·8
J	100/25	28·58	88·9	23·9	78	74·6	36·5	59·9	0·981	651·5	520·5	102·7
K	80/85	85·35	66·6	22·8	78	115·0	36·75	95·4	0·979	1292·0	341·5	77·3
L	80/70	69·70	67·7	23·3	82	118·0	36·75	100·1	0·984	1120·0	275·5	78·6
M	80/55	55·55	65·6	24·3	82	110·4	36·5	95·0	0·980	963·5	259·0	77·3
M*	80/55	56·07	69·6	22·5	76	90·0	34·0	70·2	0·986	947·3	417·5	81·9
N	80/40	39·72	69·3	23·9	82	95·3	36·5	82·2	0·980	750·8	265·0	81·8
O	80/25	25·70	70·7	24·3	82	77·6	36·5	64·5	0·9815	547·8	333·5	82·2
P	60/85	85·27	47·9	22·9	82	105·6	36·5	86·1	0·979	1,081·0	330·0	59·8
Q	60/70	69·63	48·3	23·1	78	91·1	36·25	70·7	0·984	898·3	414·0	60·4
R	60/55	55·62	48·7	23·7	78	85·5	36·25	71·7	0·978	765·0	328·5	61·6
S	60/40	41·93	50·1	22·6	74	88·7	34·0	89·1	0·987	662·3	193·0	62·9
T	60/25	26·64	50·0	22·7	76	73·2	34·0	72·9	0·989	467·5	195·0	62·4

DIX.

Cut off Pressures—Lbs. per Sq. In.		Steam-Pressures at Release—Lbs. per Sq. In.		Steam-Pressures during Exhaust—Lbs. per Sq. In.		Steam-Pressures at end of Compression—Lbs. per Sq. In.		Steam Temperatures—Degrees Fahrenheit.			
Head.	Crank.	Head.	Crank.	Head.	Crank.	Head.	Crank.	Mean Admission.	At Release.	During Exhaust.	End of Compression.
115·8	114·9	42·0	42·0	3·4	3·7	8·5	8·3	339·1	270·1	147·4	185·0
118·6	115·6	44·6	45·8	3·5	4·4	8·2	9·7	339·8	274·6	153·0	188·0
119·5	118·6	44·7	49·1	3·3	3·6	8·3	9·0	340·7	276·9	146·4	185·5
119·8	121·3	48·0	47·3	2·5	2·3	7·6	9·5	341·5	277·9	132·4	185·6
119·0	121·0	49·5	48·8	2·7	2·7	6·5	9·2	341·0	280·1	137·0	181·1
94·9	98·5	36·3	35·4	2·8	2·9	8·4	8·8	327·3	259·2	139·3	186·1
98·8	99·8	38·8	38·6	3·8	4·0	8·5	9·2	327·8	265·1	152·9	187·5
99·8	101·1	40·4	38·7	3·0	2·9	5·5	7·8	328·1	266·4	141·0	174·3
99·8	101·2	38·0	37·8	4·4	4·1	7·3	8·5	328·0	263·9	157·9	182·3
100·1	102·0	40·3	40·1	2·9	2·9	6·3	7·5	329·4	267·5	140·1	176·2
101·9	103·2	41·0	41·3	3·3	2·9	5·3	7·5	329·5	268·8	142·8	174·3
102·0	103·2	43·6	42·5	2·6	2·7	5·7	8·2	329·5	271·3	137·0	176·2
76·5	76·4	31·0	29·9	3·5	3·0	5·3	9·3	309·4	251·2	144·5	178·7
78·1	78·7	32·2	30·9	3·5	3·0	5·7	9·3	310·6	253·1	144·5	179·3
76·5	77·6	35·2	34·0	3·3	2·3	4·5	7·9	309·5	258·5	138·5	171·5
79·9	81·7	31·7	32·3	3·2	3·7	8·9	8·6	313·5	254·0	147·2	186·8
80·2	83·4	37·1	35·3	2·9	2·3	4·1	8·8	313·3	261·2	135·5	173·5
81·9	82·4	39·3	37·3	2·6	1·9	3·9	8·1	313·7	264·6	130·9	170·2
59·2	59·3	24·8	23·8	3·5	2·9	5·9	9·2	292·2	238·5	144·0	180·2
59·9	60·8	24·6	23·8	2·8	2·7	6·5	7·7	293·0	238·3	137·0	176·2
62·2	60·9	25·1	24·3	2·5	2·0	6·1	7·2	294·1	239·3	130·1	174·5
63·3	62·5	28·5	27·2	3·8	3·3	8·6	9·5	295·6	246·2	148·7	188·9
62·4	62·3	30·6	29·1	3·2	3·1	8·7	9·6	295·0	250·1	143·4	189·2

Reference Letter.	Intended Abs. Steam-Pressure / Revs. per Min.	Range of Steam Temperature—Degrees Fahrenheit.			Density of Steam.					
		Admission to Release.	Admission to Exhaust.	End of Exhaust to Admission.	At Cut-off from Diagram.		At Release.		At End of Compression.	
					Head.	Crank.	Head.	Crank.	Head.	Crank.
A	120/85	69·0	191·7	154·1	0·260	0·263	0·102	0·102	0·023	0·022
B	120/70	65·2	186·8	151·8	0·270	0·264	0·108	0·110	0·022	0·026
C	120/55	63·8	194·3	154·2	0·272	0·276	0·108	0·118	0·022	0·024
D	120/40	63·6	209·1	155·9	0·273	0·276	0·105	0·114	0·020	0·025
E	120/25	60·9	204·0	159·9	0·271	0·276	0·119	0·117	0·018	0·024
F	100/85	68·1	188·0	141·2	0·219	0·227	0·089	0·087	0·022	0·023
F*	100/85	62·7	174·9	140·3	0·228	0·230	0·095	0·094	0·023	0·024
G	100/70	61·7	187·1	153·8	0·230	0·233	0·098	0·094	0·015	0·021
G*	100/70	64·1	170·1	145·7	0·230	0·233	0·093	0·094	0·020	0·023
H	100/55	61·9	189·3	153·2	0·231	0·235	0·098	0·097	0·017	0·020
I	100/40	60·7	186·7	155·2	0·234	0·237	0·100	0·100	0·015	0·020
J	100/25	58·2	192·5	153·3	0·235	0·237	0·104	0·103	0·016	0·022
K	80/85	58·2	164·9	130·7	0·179	0·179	0·077	0·074	0·015	0·025
L	80/70	57·5	166·1	131·3	0·182	0·184	0·079	0·076	0·016	0·025
M	80/55	51·0	171·0	138·0	0·179	0·181	0·086	0·083	0·013	0·021
M*	80/85	59·5	166·3	126·7	0·184	0·190	0·078	0·079	0·024	0·023
N	80/40	52·1	177·8	139·8	0·187	0·194	0·091	0·086	0·011	0·023
O	80/25	49·1	182·8	143·5	0·191	0·192	0·096	0·091	0·011	0·022
P	60/85	53·7	153·7	112·2	0·141	0·141	0·062	0·060	0·016	0·024
Q	60/70	54·7	156·0	116·8	0·142	0·144	0·062	0·060	0·018	0·021
R	60/55	54·8	164·0	119·6	0·147	0·144	0·063	0·060	0·017	0·019
S	60/40	48·7	147·4	109·9	0·150	0·150	0·071	0·071	0·023	0·023
T	60/25	44·9	151·6	105·8	0·148	0·148	0·076	0·072	0·023	0·025

Cut-off: per cent. of Stroke.		Number of Expansions.	Mean Effective Pressures—Lbs. per Square Inch.		Total I.HP.	Wet Steam per I.HP. per Hour—Lbs.	Dry Steam per I.HP. per Hour—Lbs.	Wet Steam used per Revolution—Lbs.	Dry Steam used per Revolution—Lbs.	Total Weight of Fresh Steam present at Cut-off, from Indicator Diagram—Lbs.	Weight of Fresh Steam present at Cut-off per hour, from Diagram—Lbs.
Head.	Crank.		Head.	Crank.							
30·9	30·3	2·82	77·28	75·64	72·66	23·7	23·4	0·338	0·333	0·251	1281·0
31·6	31·9	2·73	81·03	80·18	60·38	24·1	23·8	0·363	0·357	0·266	1067·3
31·0	34·6	2·67	78·81	83·78	50·27	24·7	24·5	0·375	0·372	0·275	908·6
32·1	31·1	2·75	83·41	83·83	37·96	25·3	24·9	0·395	0·389	0·272	661·7
32·5	33·6	2·65	83·71	86·83	25·35	27·6	27·2	0·439	0·433	0·281	448·7
31·3	29·4	2·84	64·80	64·33	61·30	24·5	24·0	0·295	0·289	0·213	1085·0
33·4	32·8	2·65	68·59	66·65	63·44	25·0	24·6	0·315	0·311	0·235	1181·5
33·1	32·4	2·67	69·85	68·96	51·45	25·4	25·0	0·327	0·322	0·237	940·2
32·3	31·1	2·74	67·22	65·92	51·67	25·7	25·4	0·319	0·315	0·229	953·0
32·3	32·1	2·71	69·57	69·57	42·69	25·5	25·0	0·330	0·324	0·234	771·0
32·3	32·0	2·71	71·35	71·19	31·30	26·9	26·3	0·357	0·349	0·237	559·8
32·2	30·8	2·76	72·93	72·21	23·21	28·1	27·5	0·380	0·372	0·233	400·2
32·6	31·6	2·71	51·27	50·48	48·58	26·7	26·1	0·252	0·247	0·179	915·1
32·8	31·6	2·71	52·53	52·15	40·79	27·5	26·8	0·268	0·262	0·183	765·3
37·0	36·5	2·43	55·53	55·56	34·54	27·9	27·3	0·289	0·283	0·202	672·0
31·4	31·1	2·77	54·19	53·51	33·46	28·3	27·9	0·282	0·278	0·182	613·2
34·8	32·4	2·62	58·93	57·34	25·84	29·1	28·5	0·315	0·309	0·199	473·7
33·4	32·8	2·65	60·15	55·08	17·112	32·0	31·4	0·356	0·349	0·197	303·6
33·4	32·6	2·66	38·94	38·98	37·13	28·4	27·8	0·211	0·207	0·143	732·3
33·0	31·3	2·72	40·05	40·18	31·18	28·8	28·3	0·215	0·212	0·142	595·0
32·1	30·2	2·79	40·16	39·98	24·92	30·7	30·0	0·230	0·225	0·140	468·6
33·6	32·6	2·65	43·50	41·74	19·99	33·1	32·7	0·263	0·260	0·151	380·7
34·1	32·2	2·65	44·90	43·13	13·12	35·7	35·3	0 292	0·289	0·150	240·0

Reference Letter.	Intended Abs. Steam-Pressure / Revs. per Min.	Weight of Steam condensed per Revolution during Admission—Lbs.	Percentage of Fresh Steam uncondensed at Cut-off.	Heat-Units given to Cylinder-Walls per Revolution during Admission.	Total Weight of Fresh Steam present at Release from Indicator Diagrams—Lbs.	Weight of Steam re-evaporated during Expansion per Revolution—Lbs.	Percentage of Fresh Steam uncondensed at Release.	Weight of Fresh Steam present at Release per Hour, from Diagrams—Lbs.	Surface exposed during Admission, per Revolution—Sq. Ft.
A	$\frac{120}{85}$	0·082	75·5	71·35	0·276	0·025	83·0	1409	10·79
B	$\frac{120}{70}$	0·092	74·3	80·24	0·295	0·030	82·7	1185	10·97
C	$\frac{120}{55}$	0·097	74·1	84·40	0·308	0·031	82·7	997	11·14
D	$\frac{120}{40}$	0·117	69·9	102·2	0·313	0·041	80·4	762	10·95
E	$\frac{120}{25}$	0·152	65·0	132·5	0·322	0·041	74·4	515	11·18
F	$\frac{100}{85}$	0·077	73·5	67·6	0·238	0·025	82·4	1212	10·70
F*	$\frac{100}{85}$	0·076	75·5	67·07	0·255	0·021	82·1	1282	11·18
G	$\frac{100}{70}$	0·085	73·5	75·3	0·264	0·027	81·9	1047	11·13
G*	$\frac{100}{70}$	0·086	72·7	76·09	0·251	0·022	79·7	1041	10·96
H	$\frac{100}{55}$	0·090	72·2	79·4	0·267	0·033	82·3	878	11·04
I	$\frac{100}{40}$	0·112	67·9	98·7	0·273	0·036	78·2	642	11·05
J	$\frac{100}{25}$	0·139	62·5	122·0	0·283	0·050	76·0	485	10·93
K	$\frac{80}{85}$	0·069	72·2	61·6	0·204	0·026	82·6	1046	11·02
L	$\frac{80}{70}$	0·079	69·9	70·5	0·211	0·028	80·6	884	11·04
M	$\frac{80}{55}$	0·082	71·1	73·1	0·203	0·001	69·6	676	11·76
M*	$\frac{80}{55}$	0·096	65·5	85·6	0·213	0·030	76·5	717	10·88
N	$\frac{80}{40}$	0·111	64·3	98·7	0·242	0·043	78·2	577	11·27
O	$\frac{80}{25}$	0·152	56·4	136·0	0·255	0·059	73·2	394	11·18
P	$\frac{60}{85}$	0·063	69·4	57·6	0·164	0·021	79·8	842	11·17
Q	$\frac{60}{70}$	0·069	67·3	62·8	0·164	0·021	77·3	680	11·03
R	$\frac{60}{55}$	0·084	62·4	76·5	0·167	0·0279	74·4	558	10·87
S	$\frac{60}{40}$	0·108	58·2	97·9	0·187	0·035	72·0	469	11·18
T	$\frac{60}{25}$	0·139	51·9	125·9	0·199	0·049	68·9	318	11·18

(*Students' Paper No. 352.*)

(*Abridged.*)

"Timbering in the Ampthill Second Tunnel."[1]

By EDWARD EWING MATHESON, Stud. Inst. C.E.

THE widening of the Midland Railway between Kettering and London will be completed by the construction of a second tunnel at Ampthill, 40 miles, and another at Elstree, 12 miles from London. The new tunnel at Ampthill is 717 yards in length, and penetrates a hill the summit of which is 88 feet above the rail-level. It has been constructed entirely by means of three shafts sunk from the surface, the driving of a heading through between the faces being inadmissible on account of the long cuttings in progress at each end of the tunnel and of the treacherous nature of the ground on being exposed to the air.

The position of each shaft having been set out upon the surface and indicated by pegs driven at four points, the sinking was proceeded with, the shafts being excavated to the outside diameter of the brickwork, 12 feet 4½ inches. This diameter was closely adhered to, in order that as small a space as possible should be left between the finished brickwork and the ground behind. As the shafts were sunk the sides were lined with poling-boards, 7 inches wide by 1¼ inch thick, Figs. 1, Plate 8, closely packed all round, and supported by temporary curbs placed 3 feet apart. These were made up of two 3-inch layers of pine "sweeps," or segments, eight in each layer, the sweeps in the upper ring or layer breaking joint with those beneath. The outsides of the curbs were shaped to the curve of the shaft, and they were kept in position by 3-inch pine props, six between each pair. When a depth of about 30 feet had been attained, a permanent curb was inserted, being constructed of elm, which was found to be stronger and more durable than pine for the purpose. The brickwork was then built on this permanent curb, and was carried up to the

[1] This Paper was read and discussed at a Students' meeting on the 11th of January, 1895.

top of the shaft, the poling-boards, props, and temporary curbs being removed ahead of it. The solid ground under the permanent curb was excavated at six points around it, to allow of the insertion of strong 8-inch square pine props to support the brick-work, which were well wedged up on foot-blocks and raked back from it. By the same process the excavation, timbering, and lining for another length of shaft were proceeded with, the brickwork being carried up to the bottom of the finished portion above, and passing for a height of 4½ inches in front of the curb supporting it. Between the last curb and the level of the bottom of the tunnel invert, a length of 33 feet, the shaft was very strongly timbered in a rectangular form, 10 feet square, with pine timbers, in order to support for some time the greater part of the weight of the shaft above. This timbering was left in until the side-length was completely excavated, timbered, and bricked. The brickwork of the shaft was 14 inches thick, and was enlarged to 18 inches for a height of 2 feet above the curbs. It was faced with specially radiated blue brindled bricks, the back-work being of ordinary red bricks. At three places the shaft-lining was stepped out into bands 2 feet 3 inches thick, to serve as supports to relieve the "eye" of the shaft of some of the weight above it, and to steady the shaft against lateral movement.

The lower part of the shaft having been securely timbered, the mining of the tunnel was commenced by the excavation of the side-length of 12 feet, next the shaft, Fig. 2. In this length there were two faces to be timbered, the leading-face and the face adjoining the shaft. About 8 feet below the top of the shaft-timbering a heading 7 feet square was driven for a length of 15 feet, and was timbered with head-trees 10 inches by 6 inches, placed 3 feet 6 inches apart and supported by side-trees 6 inches in diameter. The sides and top of the heading were close-poled with 7-inch by 1-inch boards driven tight with wedges. When the heading was finished, two crown-bars, 16 inches in diameter and 19 feet long, one on each side of the centre of the heading, were placed in position, the head-trees and poling-boards being left in above them, and the bars propped up temporarily by back-props 9 inches in diameter. The heading was now gradually extended in width and the side-trees removed, until there was space for the insertion of one more bar on each side, and this was propped in its turn. These four bars were each now re-propped on leading "nippers," 5 feet 6 inches long and 12 inches in diameter. A "nipper-sill" was then laid in, and "back-nippers" were propped from it to support the bars, all the nippers raking towards the length of the bars, and a

back-prop, 12 inches in diameter and 8 feet long, being then inserted under each bar. The heading thus widened merged into the main excavation, and the mining of the length was continued, one more bar being put in on each side, followed by four "liners," or ordinary bars. At this stage the top sill, 14 inches square, made in two parts, scarf-jointed in the middle, and fastened together with a wooden key and iron straps, was drawn into place, a "saddle," 12 inches by 6 inches and 12 feet long, being placed on the top of the sill, and fastened to it by two iron straps. The six top bars or draw-bars were supported from the "saddle" by sill-props 10 inches in diameter. The other bars, except those next the sill-ends, which were blocked up, were propped off the sill, all the props on the sill and saddle radiating out to the curve of the arched excavation. The sill "liners" or stretchers now followed, namely, one at each side and two in the centre, 12 feet apart, and were taken across to the corresponding sill of the other face-timbering. The excavation of the clay now proceeded by picking and wedging only, no blasting being allowed, to avoid damage to the adjoining shaft. When the middle sill-level was reached, seven back-props 6 inches square were inserted, with slack-blocks 18 inches by 9 inches by 4 inches under each. These props were raked back from the position of the middle sill, their tops being let into the sill above, and poling-boards were closely packed behind them. Two more liners followed, and the middle sill, similar to the top sill already described, was fixed in place, wedges and packings being tightly driven between it and the blocks under the back-props; tie-pieces were also raked from the sill-top against the back-props. Eight vertical props 6 inches square were now put in position between the top and middle sills, those nearest the sides being under the ends of the top sill. An extra prop was added and raked up from the sill to support the "liner" next below the top sill, a raker or angle-strut being also fixed from the liner up to the nearest upright. The bar above the middle sill was propped from it, and secured by a wedge driven between the bar and the sill-prop next to it. The sill-stretchers were then fixed to the sill opposite as before. Back-props similar to the last were now inserted under the middle sill; and when the sides were reached, the bottom sill was drawn into position, the uprights between the two sills following. One more bar then followed on each side, being strutted off the sill and up to the top of the nearest sill-prop. The sill-stretchers were fixed in place, and the mining for the invert was proceeded with, no timbering being here needed, as the curve was shallow. Behind all the bars down to the middle sill poling-boards were

fixed, those above the draw-bars being packed very closely so that the ends butted up to each other at the centre of each bar, to prevent the boards being dragged with the bars when these were drawn forward for the next length. The boards behind the other bars were not so closely packed, and their ends overlapped. Between the fourteen top bars short stretchers 6 inches in diameter were fixed, about 4 feet apart, and two or three stretchers were inserted between the others. Numerous "jack-pages," "driving-wedges," and "slack-blocks" were used in fixing the work, as much depended on tight wedging to make good the timbering. The bars were known by number, the two bars at the top being called "crown-bars," the next on each side "fourths," and so to the fourteenth, the even numbers only being used. The face-timbering farthest from the shaft was left in until the excavation of the next length was ready at each level to receive it. The timberwork was the same for the two faces in the side-length, except that at the face next to the shaft, no other props were used to support the crown-bars at the top sill-level than those from a nipper-sill laid in at the back and from the sill itself. The brickwork was then proceeded with. The side-length was completed first, in order to give more room for the turning of the extra long "shaft-length." All the material excavated and that used in timbering and bricking the side-length was taken through a space less than 4 feet square in the shaft timberwork.

The side-length being finished, the shaft-length was prepared. This length, Fig. 3, was 18 feet 6 inches long, and included in it the "eye" of the shaft. A heading was driven and the excavation proceeded, the material being taken out from behind each side of the shaft-timbering as well as the thin wall between the shaft-and the side-length. The face-timbering was similar to that of the side-length, but with the addition of two long sill-rakers 15 inches square from the top and middle sills. They were bird-mouthed at the sills, being raked back and wedged up in an opening cut-out in the brickwork of the side-length invert. The side-timbering was somewhat different on account of the greater length and weight to be supported. The liners at the sides were at one end wedged up against the brickwork of the side-length, the draw-bars being packed up from the arch; at the face-end of the length the bars were propped from the sills in the usual way. Above the top sill, the bars were of a special length of 25 feet, there being no "second" or crown-bars, the space which they would have occupied being taken up by the "skep" in passing up and down the shaft. Between the "fourth" bars, which were kept apart by stretchers

6 feet long and 12 inches in diameter, and the permanent curb carrying the shaft-lining, raker-props were inserted to bring the weight of the shaft down upon these bars. The original shaft-timbering was gradually removed as the other timberwork took the weight of the shaft, half of which was supported by the ends of the bars resting on the brickwork, almost under the shaft, and half by an intermediate top and middle sill, props being fixed between them and inserted also between the top sill and the bars. The lower of the two sills was supported by four props 11 inches square blocked up from the invert-bottom. These intermediate sills were further strengthened by two long struts 10 feet apart in the middle of each sill, raked back to and wedged up against the brickwork. The brickwork of the length was then put in, no iron curb being used for the eye of the shaft.

The running-lengths, Figs. 4, namely the ordinary repeated 12-foot lengths, were, with some differences in detail, excavated, timbered, and bricked in a similar way to the side-lengths. There was in these lengths only one face to timber, for at the other end was the brickwork of the last finished length, against which, as in the shaft-length, the ends of the bars were fixed. Sill-rakers were also used, but they were shorter than those already described. In the timberwork the six bars at the top were drawing-bars, those for every new length being drawn forward into the heading, from their position on the top of the arch of the last length, the spaces left by them between the brick packings being filled in with dry rubble. In order to provide the necessary space on the top of the arch for the drawing-bars, the excavation was taken out 1 foot 9 inches higher than that required for the lining as far as the sixth bar, being then tapered off to the exact dimensions for the brickwork at the springing of the arch. This vacant space or "sweeps" on each side was tightly filled to the top with brickwork in mortar. As the excavation of each new length reached in turn the sill-levels of the old face, the sills and the props from them were hauled over and re-fixed in position at the new face. Most of the excavation in the running-lengths was done by blasting, tonite in the form of candles with fuses attached being used, and long holes radiating towards each other being bored by hand to receive them. Six days were occupied in mining one length, and for this about 18 lbs. of explosive were used. Great care was taken that explosions should not be fired too close to the side walls, to prevent cavities being formed in them, which would endanger the safety of the work and also necessitate extra brickwork. During the mining and widening of the headings

the lumps of excavated material were thrown down into the tunnel below, the men engaged in filling the trucks being protected from them by a "gate" of timbers strung together with chains.

The tunnel fronts are bell-mouthed and were built before the cuttings had been completed. Manholes, Figs. 5, were built in the sides at distances of 33 feet apart and alternately on opposite sides of the tunnel. The shafts remain as permanent ventilating-shafts.

The Paper is accompanied by seven sheets of tracings from which Plate 8 has been prepared.

OBITUARY.

WILLIAM BARRINGTON, who belonged to an old and well-known Limerick family, was born on the 14th of March, 1825. At the age of twenty he became a pupil of Sir John Macneill,[1] under whom he was afforded an opportunity of taking a prominent part in the development of the railway system in Ireland. During the latter portion of his pupilage he acted as Resident Engineer on the Great Southern and Western Railway from Dundrum to Kilmallock, a section of 23 miles, and in 1850 was engaged in a similar capacity on the construction of Cork Tunnel, $\frac{3}{4}$ of a mile in length, a work of considerable magnitude in Ireland in those days.

From February, 1851, to September, 1852, Mr. Barrington served as an Assistant Engineer on the Killarney Junction Railway, under the late Mr. W. R. Le Fanu,[2] having responsible charge of, first, 10 miles and then 20 miles from Mallow to Millstreet. He acted in a similar capacity from 1854 to 1859, under Mr. Le Fanu, on the Limerick and Foynes Railway, 27 miles in length. Mr. Barrington was next Chief Engineer of the extension of the Waterford and Limerick line from Castle Connell to Killaloe, a length of $7\frac{1}{2}$ miles. Among the railway works which he also constructed between 1860 and 1884 may be mentioned the Rathkeale and Newcastle Junction (10 miles); the Limerick and Kerry (43 miles); the Ilen Valley and the Bantry extension, both branches of the Cork and Bandon line; and the West Clare. During that period he was likewise largely connected with the arterial drainage system of Ireland, and designed and carried out, as Chief Engineer—in conjunction with the late Mr. Thos. Fosberry and the late Mr. W. S. Cox—the drainage of the Mulkear district, one of the most extensive and successful works in the country.

After 1884 Mr. Barrington was unfortunately not able to undertake much work. The shock of his wife's sudden death was the cause of creeping paralysis, which, gradually increasing, rendered him a complete invalid for the last seven years of his life. He was released from suffering on the 12th of January, 1895.

[1] Minutes of Proceedings Inst. C.E., vol. lxxiii. p. 361.

[2] *Ibid*, vol. cxix. p. 395.

Mr. Barrington's ability as an engineer was considerable, while his unvarying kindness and consideration to those working under him, and his pleasant manner and keen sense of humour, made him universally popular. He was elected a Member on the 6th of February, 1872.

THOMAS FLETCHER CHAPPÉ DE LEONVAL was born on the 3rd of December, 1824, at Hulme, near Manchester. At four years of age he had the misfortune to fall into a caldron of boiling water, from the effects of which he did not entirely recover until he was ten. He was educated at private schools in Southport, Tutbury, Worksop and Paris.

Mr. Chappé's career as an engineer began in July, 1840, when he was articled for seven years to Sir William Fairbairn.[1] During that time he assisted Mr. Eaton Hodgkinson[2] in carrying out the well-known researches as to the crushing strains of metals and other materials,[3] and in the experiments undertaken to ascertain the best shape of tube for the Britannia Bridge. He also superintended the erection of a corn-mill for Messrs. Poynton at Oddshod in Cheshire. In 1846 Mr. Chappé's indentures were cancelled by Sir William Fairbairn in order that he might accept an appointment as an assistant engineer on the Midland Railway, in the service of which company he remained eleven years. During that time he acted as resident, under Mr. W. H. Barlow, on the construction of the branch to the docks at Gloucester, of the Birmingham extension, and of the Stonehouse and Gloucester line. The last was a work of some difficulty, as the traffic of the Great Western and Midland Railways had to be carried on while several bridges were rebuilt with elliptical cast-iron arches. One of these was an arch of 83 feet span at Standish, 6 miles from Gloucester, the erection of which was described by Mr. Chappé in a Paper entitled "Account of Experiments upon Elliptical Cast-Iron Arches,"[4] read before the Institution in 1859.

In the autumn of 1857 Mr. Chappé entered into partnership with his brother-in-law, Mr. Thomas Cross, in a cotton-spinning business carried on at the Waterloo Mills in Bolton. During the

---

[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 251.
[2] *Ibid*, vol. xxi. p. 543.
[3] Library Inst. C.E.
[4] Minutes of Proceedings Inst. C.E., vol. xviii. p. 349.

fourteen years of this partnership the number of spindles was increased from 24,000 to 40,000. Mr. Chappé then retired from business and settled in London, where he spent the remainder of his life. He died on the 14th of January, 1895, from heart disease aggravated by bronchitis. He was elected a Member on the 3rd of February, 1857.

WILLIAM BUCHAN CHRISTIE, born on the 16th of November, 1847, was educated at the Dollar Institute, near Stirling. After being engaged for twelve months, under Messrs. Formans and McCall, on the construction of the Glasgow and South Western Railway, he was appointed in July, 1869, under the Stanley regulations, an Assistant Engineer, 3rd-grade, in the Public Works Department of Bengal. In that service he practically passed his life, rising through the various grades to that of Superintending Engineer, to which he was gazetted only two days before his death.

In 1877–78 Mr. Christie rendered excellent service in connection with the Bombay and Madras famines relief works. From 1879 to 1881 he was engaged on the construction of the Teesta Suspension Bridge, situated on the road from Darjeeling to the Thibet frontier. An account of this work, written by Mr. Christie, appeared in the "Professional Papers on Indian Engineering" (vol. x. p. 181), published by the Thomason Civil Engineering College, Roorkee.[1] During the latter years of his service in the Public Works Department of the Government of India Mr. Christie was mostly occupied as Executive Engineer in the Chota-Nagpur Division, Bengal, his work consisting chiefly in widening, macadamizing, bridging, re-aligning, and improving generally all the most important roads in the Division. Portions of these roads, with gradients of 1 in 10, and surfaces like the rocky bed of a dry watercourse, had been previously impracticable for vehicular traffic. These he made comparatively easy, with gradients of 1 in 30, suitable curves and well-finished metalling.

Mr. Christie died, somewhat suddenly, at Chinsurah from an attack of dysentery on the 11th of June, 1894. He was regarded as a most energetic officer, whose thoughts were ever in his work;

---

[1] An abstract of this account appeared in the Minutes of Proceedings Inst. C.E., vol. lxviii. p. 337.

while his genial manner and sterling good qualities made him extremely popular with his assistants and subordinates. Mr. Christie was elected a Member on the 1st of February, 1887.

EDWIN CLARK[1] was well known in the engineering profession; in the first instance from his position as Robert Stephenson's chief representative in the construction of the great Britannia and Conway bridges, and from the superb work published by him in description of them; secondly, from valuable services rendered in the early history of the electric telegraph; and lastly, by general engineering works of importance, including inventions of much public utility. And, moreover, he was a man possessing a large store of scientific knowledge, which he applied with singular practical ability. But his career was of such an original character, and so unlike those ordinarily chronicled in these memoirs, that it possesses a peculiar interest, and deserves a somewhat full description.

He was born on the 7th of January, 1814. His father, who lived at Great Marlow, was a manufacturer of pillow lace (an industry for which the whole of Buckinghamshire was renowned at that period), and was moreover esteemed by his townsmen for his superior education and good sound sense.

Edwin, the eldest of three sons, went as a child to an old school in the town, and at the age of eleven was sent to a French Academy in Normandy, kept by one of the retired professors from the Military College at Marlow. He remained there three years, during which time he not only learnt Latin and geometry, but obtained such a mastery over the French language that a translation made by him of one of Walter Scott's minor works is said to have been published in France.

In 1830 he was placed with his uncle, Mr. Rippingham, a solicitor in good practice in Great Prescott Street, London, with a view to being articled; but impatient of office restraint, he employed his time chiefly in the study of a small library of scientific books which his uncle possessed; and in them he found the means of cultivating his taste for mathematics, astronomy, mechanics, chemistry and natural history, of which last subject he became very fond. He remained two years with his uncle and then

---

[1] Some of these particulars have been derived from *The South Bucks Standard*, 4 and 11 September, 1891.

returned home, having, to the great disappointment of his parents, done nothing towards becoming a solicitor.

At that time the lace-making trade of Buckinghamshire was decaying, in consequence of the application of machinery; and Mr. Clark's means were becoming so much crippled, that he could do nothing more to push on his son, who, with the exception of a little assistance to his father, led a practically idle life for four years and was regarded by all his friends as a "ne'er-do-weel." But this idleness was more apparent than real, for he was always industrious in acquiring knowledge from books or by any other means he could find. His amusements were of a scientific character; he would construct models of machines, or home-made instruments of various kinds, with which he could make practical observations in a rough but useful way.

It was during this period that he first came in contact with engineering constructive works. He took much interest, during his rambles, in the re-construction of the old Marlow lock on the Thames, the works in progress on the Great Western Railway, and the Marlow Suspension Bridge. The clerk of the works to the latter happened to be a lodger in his father's house, and allowed him access to the office, where, with quick intelligence, he learned a great deal.

But all this acquisition of knowledge, though interesting enough to the young enquirer, did not tend much towards keeping the wolf from his family door; and he was again pressed to adopt some means of earning a livelihood. In response to this he lived some time with a surgeon, and afterwards applied for an appointment in the Excise; but neither of these aims succeeded, and he ultimately became a teacher in his old school at Marlow. While thus occupied, some pupils passed through his hands who afterwards became eminent men, among whom were Dr. Butler, the present Master of Trinity, Dr. Ridding of Winchester, Dr. Warre of Eton, and Dr. Wickham of Wellington. He ingratiated himself with his more intelligent pupils by giving them interesting gratuitous lectures on botany and other scientific subjects not in the school curriculum.

He looked, however, for something higher; and he was advised to go to Cambridge, for which object he devoted a whole year to the classics (a new study for him), entered at St. Catherine's Hall in 1834, passing his little-go examination without any difficulty, and then migrated to Jesus College; but after remaining two-and-a-half years at the University, his means failed and he was obliged to return home.

He afterwards contrived to make a long tour on the Continent, supporting himself by artistic work which he learned from a companion in his travels. Returning in 1839, he obtained mathematical masterships, of a better class than formerly, from which he made income enough to help his parents, and to provide himself with a library and a stock of scientific apparatus.

After all these vicissitudes, fortune at last began to smile on him, and his introduction to this good time reads almost like an incident in a novel. It was in the period of the great railway mania, when, during the short time it lasted, everybody capable of making a survey could get work at high pay. Mr. Clark felt he was quite competent for such work, and being suddenly asked to assist in the survey of a proposed line between Brighton and Oxford, he, with the permission of the head of the school he was employed in, went at once to look after it, and expended what was for him a large sum on the purchase of a level. But the bubbles were then breaking, and he lost both time and money. He, however, was rather attracted by the idea, and as an old friend in Birmingham promised to give him an introduction to Robert Stephenson, he determined at least to try what that might do for him. In March, 1846, he called at Mr. Stephenson's office in Great George Street: it was the busiest time of the year and he was told there was little hope of getting an interview; but he persevered, and contrived, by amusing accounts of his travels and adventures, to impress Mr. Saunderson, Mr. Stephenson's secretary, so favourably, that this gentleman was induced to get him one day a stealthy entrance into the *sanctum sanctorum*. Mr. Stephenson, with characteristic courtesy, spoke with him, and also with his usual quick discrimination saw that he was a man of ability. He tried to dissuade Mr. Clark from taking to subordinate engineering work in its then depressed state; but hearing of his mathematical knowledge, he kindly offered him a few days' work in regard to a problem on which he was then engaged, namely, the nature of the strains on the great Britannia Bridge tubes, under certain hypothetical conditions. This led to discussions, in the course of which Mr. Stephenson was so struck with the criticisms and suggestions offered by Mr. Clark, that he at once placed the matter in his hands. A room was provided for him in the Great George Street office, and the result was, that in a short time Mr. Clark, a man who had received no engineering education and to whom engineering work was almost entirely new, was first entrusted with the experiments and designs, and finally elevated

to the position of absolute control, as Resident Engineer, of what was then the greatest and the boldest engineering work in the world. And Mr. Stephenson never regretted the step he had taken.

Some letters from Mr. Clark to his most intimate friends show the impression this unlooked-for good fortune made upon him, and an extract or two may not be uninteresting.

"I have had a very pleasant and satisfactory interview with Mr. Stephenson this morning. He treated me most kindly, and promised to do something or anything for me.

"I have got put into my hands by Mr. Robert Stephenson all his ideas and wishes about the intended bridge, by far the greatest work ever attempted by mortals. . . . All is at present in embryo. I am sole manager of the plans and sole calculator of all the mathematical work, and have liberty to perform any experiments. . . . I got the appointment by his own examination of me, not by mere introduction, which gives me greater hopes of success; but I am *not sanguine*.

"I have made a model of the bridge for Mr. Stephenson, and we spend every day two or three hours in chatting together on the subject. He is a delightful fellow and a very clever practical man.

"We are assailed with mathematical demonstrations of the absurdity of the attempt altogether, even from some of our own mathematical friends. All these things I have to answer and combat with, besides the work itself; so that I am kept quite in hot water. . . . I don't find anybody with courage enough to hazard me any assistance or advice, but they all presume that I am quite used to such work."

The Act sanctioning the Bridges was passed on the 30th of June, 1845, and the first stone of the Britannia Bridge was laid on the 10th of April, 1846. References continually recur to important and responsible work of various kinds performed by Mr. Clark, until the 19th of October, 1850, when the Bridge was completed and opened for the double line.

But Mr. Clark has an additional merit in regard to these Bridges, namely, that of the production of the well-known work in which their history and description are enshrined—one of the most magnificent specimens of engineering literature in existence. It is seldom that engineers who have the ability and the opportunity to carry out great works, have also the gift of describing them well, or indeed care to take the trouble required for the purpose. Fortunately Mr. Stephenson found in Mr. Clark a man not only capable of fully appeciating all the refined and complicated elements of the design, but also of putting the whole on record, fully and clearly, for the information of posterity; and accordingly

he determined to sanction and aid in the preparation of a book which Mr. Clark intended, as he said, to "preserve the history of a conception as remarkable for its originality as for the bold and gigantic character of the application;" "an engineering achievement which stands confessedly unrivalled in daring and success."

The book, in two volumes, large 8vo., with a folio of engravings, appeared in July, 1850, with the following title—

"The Britannia and Conway Tubular Bridges, with General Inquiries on Beams and on the properties of Materials used in Construction." By Edwin Clark, Resident Engineer. Published with the sanction and under the supervision of Robert Stephenson. London: Published by the Author; by Day & Son, Gate St., Lincoln's-Inn-Fields; and John Weale, 59, High Holborn.

The Author acknowledged much information gathered from many sources, as well as special theoretical investigations contributed by Mr. Eaton Hodgkinson, F.R.S.; by Mr. Charles Heard Wild, and by Mr. William Pole.[1]

The concluding passage of Mr. Clark's work may be interesting; it will show that even in so prosaic a matter he could not refrain from introducing a touch of his love for natural history. He says:—

It is indeed a source of high gratification to have been instrumental in realising so magnificent a conception of a master mind; and it is a pardonable vanity to believe that such a record of the industry of an intelligent people will increase in interest when all traces of this once busy scene shall be effaced; when the noise of the hammer has ceased, and the ephemeral village of the builders has disappeared; when the fern and the moss shall have ventured to invade even the massive pile that has displaced them; when the sea-weed, with its coral inhabitants, shall have mantled the foundations; and the wild bird, so long affrighted, shall return to its solitude, and rear its progeny beneath the marble shelter of the towers.

After the completion of his labours on the great Bridges, Mr Clark entered upon an entirely fresh field of engineering occupation, one indeed which was as new to him as the construction of great iron bridges was when he first met Robert Stephenson. This was the application of electricity to practical uses, which has since assumed such gigantic proportions.

He had, in his early youth, been much interested in the subject of electricity generally, and he has left on record an interesting account of how he came to take it up. He relates that he had, when a schoolboy at Marlow, heard a lecture given on the subject,

[1] A condensed account of these Bridges, as well as of other of his large works in iron, will be found in the "Life of Robert Stephenson." Longmans. 1864.

and he continues the account of his own proceedings as follows. He says:—

I remember that, after the lecture, this subject continually haunted me, and I was determined to know more about the wonderful agent which the itinerant lecturer had illustrated by such brilliant experiments. Now a schoolboy in my sphere had, at any rate, not much leisure time on his hands, and he had plenty of calls on the little he had. His income would be equally scanty. His stock of tools would be limited to his pocket-knife, while the only materials at his command would be of the most homely household description. I found, however, no difficulty, amid all these disadvantages, and without any previous knowledge of any other scientific subject whatever, in commencing and even prosecuting successfully the study of a subject so difficult and so mysterious as the science of electricity. I determined to make an electrifying machine, and in this step I had really made a great step in natural philosophy itself. A pickle-jar was speedily converted into a cylinder; a bung and a few screws, with a plank and a coffee-mill handle, were the means of mounting it; an old silk apron made a rubber; the mercury from a broken weather-glass, with some tin-foil, fused in a tobacco pipe, made an amalgam: and thus my first lesson in mechanics and chemistry followed rapidly in the wake of my first desire to learn a totally different subject. My Leyden jar was a common bottle filled with shot and lined with tin-foil from a package of tea, and the conductor and discharging knob were easily procured from the stem of a discarded parasol and a brass button from my corduroy jacket. You may imagine my delight on first drawing long sparks from this humble machine, and the glee with which all my friends were invited to see my success. I could not, of course, stop here. I had acquired at once a taste for knowledge, and what was even more important, I had proved how easily it was within my reach. The lesson I thus learned, and the principles I thus imbibed, have never been effaced, and I am indebted to these schoolboy impressions for all the advantages which have subsequently fallen to my lot.

The young philosopher little thought that all these schoolboy experiments would eventuate in a great practical acquaintance with electricity; but the time came when this occurred. About 1846 a company had been incorporated for the development of electric telegraphs, called the Electric Telegraph Company, and on its direction were the names, now so well known, of Cooke and Wheatstone, G. P. Bidder, Thomas Brassey, Lewis Ricardo, and Mr. Clark's special friend, Robert Stephenson. The company afterwards became "The Electric and International Telegraph Company," providing telegraphic communication for almost every railway in the United Kingdom, and entering into other large applications of electricity in various ways.

When the Bridges were approaching completion, an opening occurred for an engineer to this great undertaking, and although Mr. Clark had hitherto had no experience whatever in electrical work, yet Robert Stephenson, having now had many years' acquaintance with him, unhesitatingly recommended him to the

post, and in August, 1850, he was appointed, accordingly, Engineer-in-Chief to the Company, a position he held for many years.

During Mr. Clark's dealings with the railway companies, he was asked by Captain Huish of the London & North Western Railway, to advise and report on a telegraphic system which would relieve and assist the heavy traffic on that line, and this led to his invention and introduction of what has ever since been known as the "Block System," of such immense importance to the traffic of the country. Mr. (afterwards Sir George) Findlay (manager of the North Western Railway) said, writing in 1891:—

> "The electric telegraph had already been utilized for transmitting from station to station the times of departure of the trains; and about 1853 Edwin Clark introduced the absolute Block Telegraph System, by means of which the number of trains which may be passed over a given section of line with perfect safety, may be said to be almost unlimited."

Mr. Clark's telegraph work comprehended many other improvements, particularly in regard to the insulation of the overground wires, then in a very defective state. He invented and patented the "Dew Cap Insulator," which afterwards came into universal use. Many other advantageous changes in the details of the novel and complicated apparatus required for the electrical work were due to him, and to his brother, Mr. Latimer Clark, F.R.S., who, after aiding him on the staff of the Bridges, succeeded him in his electrical position.

It need hardly be said that after the prominent position Mr. Clark had occupied in the matters above mentioned, his high professional acquirements received general recognition, and he became celebrated, not only as a clever and experienced practical engineer, but also as one who was decidedly above the average in the scientific principles of his profession. He had therefore large calls on his services, and for the remainder of his life he became engaged in engineering works of great magnitude and variety, which, however, do not here require more than a brief mention of such as were most important.

During this time, railway works of enormous extent were being carried out, largely by English engineers or contractors in foreign countries; and as his fame in regard to iron bridges stood so high, Mr. Clark was engaged to design them in legions, particularly for great systems of railways carried out by Mr. Brassey in Central and Southern Europe. Exceptionally large and important bridges were the Aire Bridge on the York and North Midland Railway; the Warrington Bridge and the Walton Viaduct over the Mersey

on the Warrington and Altrincham line; the Rubion Bridge on the Lyons and Mediterranean line; the Arnheim Bridge over the Rhine on the Dutch Rhenish Railway; the bridges over the Isère and the Arc on the Victor Emmanuel Railway from France by the Mont Cenis into Italy; and the reconstruction of the Saône Bridge at Lyons.

He laid a new wrought iron roof over Exeter Hall without disturbing the original structure, and he did much engineering work in the Crystal Palace at Sydenham. He was also engaged by the Admiralty to improve the navigation of the Menai Straits by the removal of the Swelley Rocks, which had long impeded the passage.

He was selected as negotiator by the Réunion Financière (an association of capitalists of which the Baron James Rothschild was the head) to examine and report on the whole system of Russian Railways and their extension. This was at the special invitation of the Emperor, and he travelled over a large portion of the Russian Empire, residing some time in St. Petersburg.

He was engineer and partly constructor of the fine harbour at Callao in Peru, and also of piers and wharves at Colon (Isthmus of Panama) for the Royal Mail Company.

He was engineer of numerous railways and other public works, including the line from Smyrna to Aïdin, now called the Ottoman Railway. At one time he became a contractor for works on a very large scale. Giving evidence in 1873, he stated that his contracts, then in hand or completed, amounted in the aggregate to £5,532,000. These contracts were all said to be very successful (owing no doubt to his skilful and experienced management), and gave employment to a large staff of assistants and pupils. In one of them, in 1873, a ship called the "Northfleet" was wrecked with a loss of 300 lives while carrying workmen and stores to Tasmania. He was, among other things, the contractor for the Marine Canal from Cronstadt to St. Petersburg. He joined in the purchase from the Spanish Government of the Rio Tinto Copper Mines, and constructed the railway from the mines to the Port of Huelva.

One of Mr. Clark's most brilliant engineering achievements was his invention and perfecting of the "Hydraulic-Lift Graving Dock," now so well known. The history of this dates from about 1857, when, the Victoria Docks at Blackwall being just completed, it was part of the plan of Mr. Bidder, the engineer, to construct a graving dock as an adjunct to that establishment. Serious diffi-

culties however arose, and it occurred to Mr. Clark that vessels might be lifted bodily out of the water for repair or examination by the same means which had been adopted in raising the huge tubes of the great bridges, namely, hydraulic-power. The problem was simply to raise a given weight to a moderate height in the most rapid and economical manner, and there appeared no reason why a vessel should not be dealt with in the same manner as any other load. The proposal was duly considered, and ultimately a structure of the kind was built in the Victoria Docks by Mr. Clark for an independent company under the title of "The Thames Graving Dock Company." The process consisted of two distinct operations—first the direct raising of the ship upon a shallow pontoon; and secondly the transport of the vessel on the pontoon to any convenient position for its repair.

After the success of the plan had been established by the working at the Victoria Docks, Mr. Clark wrote a Paper, fully descriptive of the invention and of the apparatus, which was read before the Institution on the 27th of February 1866.[1] It made a considerable sensation, caused a lively discussion during four evening meetings, and was awarded a Telford medal.

Structures of this kind have since been erected at Bombay, at Malta, and in many other places. The same system has also been applied as a canal lift, and has been carried out in Cheshire, on French and Belgian Canals, and for the Chignecto Marine Railway in Canada.

The success and popularity of Mr. Clark's Paper in 1866 prompted him to follow it with one of another and more general kind. In his work on the Bridges he had given great attention to the scientific principles which should guide engineering works, and it occurred to him as advisable that Papers of this character should be occasionally presented to the Institution. Accordingly, on the 12th of May, 1868, he communicated one (intended to be the first of a series) on "Engineering Philosophy."[2] The following extracts will show his object. He said:—

The engineer of the present day is generally too incessantly occupied to afford much time for theoretical discussion. . . . It has, indeed, been truly observed that the application of the principles of Natural Philosophy to practical purposes is the essential province of the engineer. There is, however, a possibility that in taking its rank among kindred sciences, the too rigid application of the "cui bono" to civil engineering may not only detract from its dignity,

[1] Minutes of Proceedings Inst. C.E., vol. xxv. p. 292.
[2] *Ibid*, vol. xxvii. p. 554.

but, what is of far more importance, may narrow its scope and interest, and forfeit its support from that high and numerous class who love science for its own sake.

It is on these grounds that the Author ventures to hope that some interest would attach to a series of Papers devoted, not so much to the special application of those philosophical principles which form the basis of practice, as to the consideration of the principles themselves. Numerous questions occur which could be more effectually discussed in their abstract capacity than in connection with the practical applications out of which they arise.

The Author would suggest that a series of such essays might be appropriately called "Tracts on Engineering Philosophy."

The subject of this first Paper was one of great importance, namely, "The Durability of Materials;" it was treated in an eminently philosophical spirit, and contained excellent and logical reasoning, founded upon careful and extended observation; and it is effectively a model for essays of the kind. Unfortunately, however, no further Paper of this series appeared.

Mr. Clark had at one time a remarkable subject in view for an essay, namely, "On Engineering Failures," and few engineers of experience can doubt how much instruction, for students at least, could in good hands, be worked out of such a theme. But unfortunately, the identifying, specifying, and illustrating the particular examples which must have been brought forward, offered difficulties and stumbling blocks so formidable as to extinguish the idea.

Mr. Clark took great interest in several scientific subjects not directly connected with the profession. One was astronomy, which he studied much, working very frequently at observations of various kinds. And so impressed was Robert Stephenson with his skill that he presented him with a cheque for £2,000 towards establishing an observatory where he could work with more success than with his smaller instrumental apparatus. Mr. Clark was a great student of natural history, and, though not what is called a collector in any of its special branches, he acquired, by keen observation, a great store of knowledge on the subject. It is remarkable that in the familiar letters, previously mentioned, written at the time when his new occupation on the Bridges might be supposed to engross all his attention, large portions were devoted to microscopic investigations on natural objects of various kinds.

He was elected an Associate on the 3rd of December, 1850, and was transferred to the rank of Member on the 3rd of April, 1855.

About 1876 he retired from active business and made a voyage

of pleasure to South America, which occupied him two years, visiting Argentina, Paraguay, Uruguay, and many districts very little known. After his return in 1878 he published an account of his visit, which is a model of scientific description in a popular style in a small volume.[1]

After this he settled down at Cromwell House, Marlow, where he resided during the remainder of his life, taking great interest in local affairs. He either formed or encouraged a Mutual Improvement Society, of which he was for some time President, and gave frequent lectures on scientific subjects, often containing most interesting personal reminiscences of his experience and career. He was fond of music, and established local practices and concerts which were very popular and successful. In 1889 he was appointed a magistrate for the county, and he served actively on the bench as long as his health allowed. He died at Marlow on the 22nd of October, 1894.

GEORGE GARNETT, Engineer and Manager to the Ryde Gaslight Company, and Chairman of the Ventnor and Shanklin Gas Companies, was essentially a self-made man. Born at Portsea on the 2nd of January, 1820, he entered at the age of thirteen a large drug establishment in Portsmouth. From that time until 1848 he was engaged in the business of a chemist and druggist, at first in London and subsequently at Bath. A series of descriptive articles on the manufacture of gas, published in the *Hampshire Guardian*, obtained for him a post in the service of the Portsea Island Gas Company, of which he became Engineer and Manager in 1853. During his connection with that company he carried out works costing £30,000 and increased the output of gas to 500,000 cubic feet per day.

In 1858 Mr. Garnett was appointed Engineer and Manager to the Ryde Gaslight Company, which post he held for upwards of thirty-six years. During that time the annual output of gas was increased from 9,000,000 to 63,000,000 cubic feet. He also acted as Engineer to the Ventnor Gas and Water Company, and to the Shanklin, Sandown, and Havant Gas Companies, and subsequently became a Director of one or more of these undertakings and also of the Ryde Pier Company. In addition to his official duties he identified himself with all movements tending to the

---

[1] "A Visit to South America." Dean and Son, London, 1878.

welfare of the town of Ryde and for nine years acted as Chairman of the local School Board. In 1889–90 he served as President of the Gas Institute, before which he delivered the usual inaugural address.[1]

Mr. Garnett died from apoplexy, after only three days' illness, on the 18th of December, 1894. He was elected an Associate on the 1st of March, 1859, was subsequently placed among the Associate Members, and was transferred to the class of Member on the 3rd of May, 1881.

ARTHUR JACOB, son of Dr. Jacob, a well-known oculist, was born near Dublin on the 4th of July, 1831. In 1855 he graduated Bachelor of Arts at Trinity College, Dublin, and in the following year obtained the diploma of the Engineering School. He then entered the service of the Bombay Public Works Department as an Assistant Engineer, and until June, 1859, was in charge of the Belgaum and Goa Military Road Works. From April, 1860, to December, 1861, he was engaged on the Krishna Irrigation Surveys, and in October, 1862, he was appointed Executive Engineer for Irrigation, which post he held for two years. During that time he carried out independently the Rewarree Irrigation Works and the greater part of the Krishna Irrigation Head Works and Dams. In November, 1864, private reasons induced him to resign the service and to return to England.

From January, 1866, to June, 1867, Mr. Jacob was employed by Mr. Baldwin Latham, as principal assistant on the Croydon Drainage and Water Works. He was then for five years Engineer to the Local Board of Health of Bromley, Kent, during which time he carried out the main drainage of a portion of that district. In 1871 he contributed to the Institution a useful Paper, entitled "The Treatment of Town Sewage,"[2] for which he was awarded a Telford Premium. Mr. Jacob's next appointment was that of Engineer to the Corporation of Barrow-in-Furness, which post he held from March, 1872, until 1877. During those five years he reconstructed the main drainage and carried out other extensive public improvements, the expenditure on works executed directly under his charge amounting to about £20,000 per annum.

---

[1] Trans. Gas Institute, 1889, p. 5.

[2] Minutes of Proceedings Inst. C.E., vol. xxxii. p. 371.

A wider scope was now afforded for Mr. Jacob's energy. In 1877 he obtained, by competition, the post of Engineer to the Corporation of Salford. In that capacity he carried out during the next fourteen years sewage disposal works on a large scale, including the laying out and development of sewage-farms, which involved extensive pumping apparatus and heavy drainage. He was also responsible for the construction of two iron bridges across the river Irwell, was frequently consulted as to drainage schemes, and assisted in various arbitration cases. In 1891 failing health compelled him to resign the service of the Salford Corporation. After four years of retirement he died at Clapham on the 7th of February, 1895. As to his professional ability sufficient indication has been furnished by the foregoing sketch. In private life he was quiet and reserved, but always kind and considerate to those around him. Mr. Jacob was elected an Associate on the 6th of December, 1864, and was transferred to the class of Member on the 21st of December, 1875.

ROBERT JONES, who died at his residence at Putney, on the 1st of January, 1895, at the ripe age of eighty-three, was the survivor of the eminent gas engineers of the last generation, among whom may be mentioned the well-known names of George Lowe, Thomas Greaves Barlow, John Evans, Thomas Hawksley and Angus Croll.

He was born in 1812, in the island of St. Christopher, in the West Indies, where his father's battery of Royal Artillery was stationed, and he came to England some years afterwards. In 1835 he began his gas experiences as assistant-manager to the Chester Gas Company, and soon became manager there. In later years he went to Worcester, to Bath and to Wolverhampton, acting also as advising or consulting engineer to many other provincial companies.

His most important work began however in 1854, when he was appointed to the Commercial Gas Company, in the East-end of London. This company was then in very low water, but Mr. Jones' energetic management, and his improvements in the processes used, produced such a rapid amelioration in its prospects as to attract general attention; and he was consulted by another large body, the London Gas Company (since amalgamated with the Gas Light and Coke Company), for which he directed the establishment of extensive new works.

In 1875 Mr. Jones carried through Parliament, in the face of strong opposition, an amalgamation of his own company with that at Ratcliff, and he was the first of the gas engineers to acquiesce in Mr. W. E. Forster's "sliding scale" system (of dividends depending on the price of gas) which has been in use in London ever since. In 1880 he retired, and his son, Mr. Henry E. Jones, who had formerly been joint engineer, undertook the duty alone, Mr. Robert Jones being appointed a member of the Board of Directors and subsequently deputy chairman. It is owing to the excellent management of the Commercial Gas Company by Mr. Jones and his son that it has preserved an independent position, and evaded absorption by amalgamation into the gigantic undertakings around it.

The best testimony to Mr. Jones's professional reputation and the respect in which he was held, was his being so frequently called on to advise or co-operate in regard to other gas undertakings. He was an arbitrator between the Surrey Company and Mr. Croll, the lessee; the directors of the Great Central Gas Company also consulted him, and he was at one time really responsible for a large share of the Metropolitan Gas supply. He also advised the old Birmingham Gas Company, and was afterwards engaged for the Corporation of Birmingham to advise on the acquisition by that body of the two Birmingham gas undertakings. He was on the direction of several minor companies the works of which he had fostered.

He took much interest in the public works and management of the metropolis; and served for many years as a member of the Metropolitan Board of Works, resigning, however, two years before the existence of that body was ended.

Mr. Jones was elected a Member on the 3rd of May, 1870.

HENRY KEMP, son of Mr. George Kemp of Cricklewood, was born on the 9th of August, 1839. Both as regards preliminary training and subsequent professional work Mr. Kemp's career was typical of that of many another English engineer during the transition period, now nearly gone by, between the making of foreign railways by English engineers and contractors, and the execution of those works by native enterprise. Intended at first for the naval profession, Mr. Kemp made a voyage or two to South America, but abandoning the idea of becoming a sailor, he next

served a pupilage of four years to Messrs. Edmund Smith and Sons, Engineers and Government Contractors, where he acquired practical experience in the carrying out of large works. He then obtained a position on Sir John Fowler's engineering staff and was engaged on the construction of the Metropolitan Railway. Tiring of office work he relinquished this position, and joining the staff of Messrs. Piercy, went out to Sardinia on the surveys of the Royal Sardinian Railway. On his return to this country he was employed on railway construction works in Wales and subsequently on fortification work for the War Office, after which he again went abroad as engineer for Messrs. Waring Brothers on the Hungarian Railways.

In 1871 Mr. Kemp rejoined Sir John Fowler's staff, and was chiefly engaged in Nubia on the surveys of the more remote desert portion of the Soudan Railway. After short professional expeditions to Spain and Russia, he returned to Egypt on irrigation studies, and then, abandoning for a time a wandering life, he entered as a partner a Continental bridge-building firm. In 1881, however, he resumed his old work and became engineer-in-chief of the Haida Pacha and of the Smyrna and Cassaba Railway. That position he held until about two years before his death, which took place on the 29th January, 1895, after only a few days' illness from pneumonia, followed by failure of the heart. Mr. Kemp's experience of the world was wide and he was a worthy representative of English engineers. He made many and lost few friends, and his death will be keenly felt by not a few of the less fortunate members of the profession whom he was always ready to befriend, either at home or abroad. He was elected an Associate Member on the 4th of March, 1879, and was transferred to the class of Member on the 25th of November, 1884.

THOMAS STUART KENNEDY, son of the late Mr. Peter Kennedy, who for many years resided at Zürich, was born on the 26th of April, 1841. After studying at Geneva and at Hanover, he served an apprenticeship at the Wellington Foundry, Leeds, becoming in 1863 a partner in the firm, which was then known under the style of Fairbairn, Kennedy and Naylor. For twenty years Mr. Kennedy had charge of the department devoted to the construction of engineering tools generally and of travelling-cranes.

Mr. Kennedy retired from the firm at the end of 1882, still

keeping in touch, however, with the engineering world through the various experiments he carried out in a small private workshop, in which he worked constantly when not abroad. He was a keen sportsman and enjoyed out-door exercise of all kinds. As a young man he was the first to ascend, in 1862, in company with Mr. Wigram and two guides, the Dent Blanche, one of the most difficult Alpine peaks. He also made an attempt to ascend the Matterhorn in the winter of 1862, in the idea that it might prove less impracticable in January than in summer. He was a member of the Alpine and Hurlingham Clubs and of the Bramham Moor and the York and Ainsty Hunts.

Mr. Kennedy died on the 17th of November, 1894, the cause being an affection of the heart from which he had suffered for some time. He was elected a Member on the 3rd of April, 1894.

CHARLES BENJAMIN KNORPP, born at Benares, India, on the 19th of September, 1838, was the only child of a German missionary stationed there, who, with his English wife, died from cholera a year or two after their marriage. The subject of this notice, after passing through the curriculum prescribed for Civil Engineers at the Royal Polytechnikum of Stuttgart, was engaged in 1859–60 on the works of the East Kent Railway, now part of the London, Chatham and Dover system. In April, 1861, he was appointed an assistant engineer in the service of the Madras Irrigation and Canal Company, and for five years was engaged in making the surveys, plans and estimates of nearly 100 miles of main canal from Rajoli to Someshwaran. He was then in charge of the Kurnool head-office from July, 1866, to June, 1867, and of the Ulloor Division for twelve months. He next assisted Mr. John Carruthers in designing, laying out and preparing estimates for the Distribution Works of the Dhoor Division and in the construction of the lower portion of the Main Canal in that division. In July, 1870, he was appointed Executive Engineer, and was then for nearly three years engaged in completing the works of the Main Canal and Distribution from Jootoor to Cuddapah, a distance of 100 miles.

On the 4th of February, 1873, Mr. Knorpp was appointed Superintending Engineer for the North Island of New Zealand, and the whole of the extensive public works then being carried out in that Island by the Government of the Colony were placed under his charge. Thus he was responsible for the location and con-

struction of nearly 500 miles of railways and of the Frances Water-race, 10 miles in length, capable of carrying 40 cubic feet of water per minute. In 1880 Mr. Knorpp resigned his appointment and retired to a property he had purchased at Ngarawahia in the province of Auckland, where he occupied himself energetically in improving the land and in planting trees. In 1889–91 he took charge for Messrs. Perry, Cutbill, De Lungo & Co. of the construction of the northern section of the Cordoba and North Western Railway in Argentina. On the completion of the works Mr. Knorpp returned to New Zealand and resided at Ngarawahia until his death, which occurred after a short and painless illness from paralysis on the 3rd of September, 1894.

Mr. Knorpp was of a retiring disposition, but those who knew him well esteemed him for the openness and straightforwardness of his character, for his varied and extensive knowledge, and for the kindness and unselfishness of his disposition. He was elected an Associate on the 6th of April, 1869, and was transferred to the class of Member on the 3rd of December, 1878.

HENRY CHRISTOPHER DIGGES LA TOUCHE, the son of the Rev. Thomas La Touche of Killanaule, in the county of Tipperary, was born on the 2nd of September, 1839. He was educated at Warwick and Cheltenham Colleges. In boyhood he displayed much mechanical aptitude, being known among his schoolfellows as "Carpenter Digges," and in early youth he constructed a lathe with slide rest which he finished with much care and skill.

Towards the end of 1860 he was apprenticed to Mr. Edward Purser, then engaged on the construction of the Smyrna and Aïdin Railway in Asiatic Turkey, and arrived in that country in December of that year. He was engaged for three years principally on survey and office work, as there was during that period but little constructive progress on that line. Among these surveys were preliminary studies of lines of railway from Varna to Rustchuk in European Turkey; and from Sebastopol to the north of the Crimea, a portion of a projected line to Moscow. At the beginning of 1864 the works of the Smyrna and Aïdin Railway were pushed on with more vigour, and Mr. La Touche was put in engineering charge of the heavy works (including two tunnels) of the northern slope of the Ephesus Pass. He remained on these

works till their completion in July 1866, when the line was opened to Aïdin and his services were no longer required.

This, as many engineers will remember, was a bad time to be thrown out of work, and Mr. La Touche did not succeed in finding employment until in 1868 he obtained an appointment under Mr. Hamilton Lee-Smith,[1] who was then forming a staff for the construction of the Lahore and Peshawur Railway under the orders of the Indian Government. He accordingly went out to India in November, 1868, and was employed for the first three or four years on surveys of the difficult portion of the Lahore and Peshawur line which traverses the "Salt Range" between the rivers Jhelum and Indus. About this time he was, with others of Mr. Lee-Smith's staff, incorporated with the establishment of the Indian Public Works Department and ranked as Executive Engineer 2nd-grade.

In 1874 Mr. La Touche went home on furlough, and on his return to India was placed in engineering charge of the Chumbul Bridge on the railway between Agra and Jhansi. This bridge is of twelve spans of 200 feet and two spans of 150 feet; making a total opening of 2,700 feet. The drainage area above bridge is about 48,000 square miles, and the floods rise to the enormous height of 96 feet. The foundations consisted of stone wells sunk to a depth of 80 feet, and the superstructure of stone piers and wrought-iron lattice-girders. He remained in charge of this work till its completion in 1881 (for the last two years as Engineer-in-Chief of the railway of which it formed a part), when he went to England on furlough and married in November of that year a daughter of the Rev. G. Huntingdon, rector of Tenby.

On his return to India he was placed in charge of the Bundelkhund Railway Surveys as Engineer-in-Chief. These surveys included that of a line from Jhansi to Manikpur which occupied two years, after which the construction of that line was commenced and carried on departmentally under Mr. La Touche's charge. One of the largest works was a girder bridge of thirteen spans of 150 feet over the River Betwa. The rise of this river in floods is 54 feet at the bridge. Early in 1885 these works were handed over by the Government of India to the Indian Midland Railway Company, and Mr. La Touche was sent to take charge of the Bellary Kistna Railway in the Madras Presidency, succeeding Mr. Henry Lambert as Engineer-in-Chief. He remained in charge of this work till his health broke down and he was obliged to go home in 1890. There were many large works on this line too

[1] Minutes of Proceedings Inst. C.E., vol. xcix. p. 352

numerous to specify, but one, in which Mr. La Touche's characteristic mechanical resource was more particularly shown, may be mentioned. This is the Dorabavi Viaduct of which the middle span is about 240 feet with the underside of the girders about 200 feet above the ravine bed. The girders of this large span were erected at the level of the foot of the piers and gradually raised along with the building of the piers in the following manner. A massive timber four-legged "stool" was firmly braced to each end of the girders. The legs of these stools worked like plungers in sand-boxes built into the piers. The girders were lifted by hydraulic jacks, and at each lift of the jacks sand was run into the sand-boxes, thus supporting the girders while the masonry was carried up and the jacks set for a fresh lift. This method worked most successfully and effected a great saving in staging.

As already mentioned, in 1890 Mr. La Touche's health broke down, and in May of that year he went home invalided, retiring shortly after from the service of the Indian Government. He never recovered his health, and was up to the date of his death (the 16th of February, 1895) subject to attacks, arising from heart disease, each of which left him weaker than the last. He was of a manly and straightforward disposition, kind and helpful in all family relations, and a staunch friend. He was in his professional work essentially practical, and, besides great mechanical ability, had considerable capacity for administration, which stood him in good stead in the appointments he latterly held. He was deservedly popular with those who worked under his orders, as his dealings with them were always marked by kindness and consideration. Mr. La Touche was elected an Associate on the 1st of December, 1868, and was transferred to the class of Member on the 9th of February, 1875.

EDWARD JOHN LLOYD, second son of the late Mr. Charles Lloyd, who for many years was Secretary to the Warwick and Birmingham Canal Company, was born on the 23rd of November, 1827, and was educated at the Birmingham Grammar School. At his own urgent request, however, he was removed from school at an unusually early age, in order that he might study engineering, for which he showed a decided taste. In 1841, therefore, he was articled for four years to Mr. James Potter,[1] under whom he was

[1] Minutes of Proceedings Inst. C.E., vol. xvii. p. 94.

engaged on the works of the Birmingham and Warwick Junction Canal (an extension of the older Warwick and Birmingham Canal), of the Brighton and Chichester Railway, and of the branch from Three Bridges to Horsham. From 1846 to 1849 he was an Assistant Engineer, under Mr. I. K. Brunel,[1] on the construction of the Oxford, Worcester and Wolverhampton Railway, having charge of the works from Dudley to Wolverhampton.

Mr. Lloyd was only twenty-two years of age, when, at the end of 1849, he was appointed Engineer to the Warwick and Birmingham, and the Birmingham and Warwick Junction Canal Companies, to which duties were added in 1869 those of Engineer to the Warwick and Napton Canal Company. As he held those posts until his death, Mr. Lloyd was thus actively connected with the canal interest of the country for forty-five years. During that period he carried out considerable works, amongst which should be mentioned specially considerable alterations to the existing pumping machinery, and the erection of extensive new plant. He re-constructed the Napton reservoirs under exceptionally difficult circumstances, and designed and erected a cast-iron bridge for the Corporation of Birmingham, flood-weirs in the Avon and in the Cole, and sluices in the Dee for the Hawarden Trustees. He also acted as Consulting Engineer to the Worcester and Birmingham Canal Company before its amalgamation with the Gloucester and Berkeley, and was frequently asked to advise the Bradford, the Basingstoke and other canal companies.

Among the Parliamentary Committees before which Mr. Lloyd from time to time gave evidence were: the Select Committee on Railway Companies Amalgamation, 1872; the Select Committee on Railways, 1881; the Select Committee on Canals, 1883; and the Royal Commission on the Depression of Trade and Industry, 1886.[2] In the year 1887 he was actively engaged before the Railway Commissioners in obtaining through tolls for the Canals between South Staffordshire and London; he was consulted by the Board of Trade with reference to the working of the Railway and Canal Traffic Act of 1888; and within a few hours of his death was engaged in re-arranging the tolls rates and charges on traffic in South Staffordshire. Mr. Lloyd expired suddenly from heart disease on the 22nd of December, 1894, while walking from his office to the railway station in Birmingham.

---

[1] Minutes of Proceedings Inst. C.E., vol. xix. p. 169.

[2] The Reports and Minutes of Evidence of these bodies are in the Library of the Inst. C.E.

His long experience, ability, and firmness of character rendered Mr. Lloyd's opinion of great value in all matters connected with inland navigation and he was universally recognised as a sound, practical engineer. He was intimately connected with the Canal Association, of which he was the oldest member, and was devoted to the interests of the Companies he so long represented. For upwards of forty years he lived at Hatton, near Warwick, where for a long period he filled the offices of churchwarden and overseer. Mr. Lloyd was elected an Associate on the 5th of December, 1871, and was transferred to the class of Member on the 15th of January, 1878.

JOHN RICHARD RAVENHILL, eldest son of the late Mr. John Ravenhill of Ashton Gifford, who was a Justice of the Peace, Deputy Lieutenant, and in 1870 High Sheriff for the county of Wiltshire, was born at Lavender Sweep, Clapham Common, on the 15th of April, 1824, and was educated at Winchester and at King's College, London. He was then apprenticed to Messrs. Miller,[1] Ravenhill & Co., in which firm his uncle, Mr. Richard Ravenhill,[2] was a partner. After serving a pupilage from 1842 to 1847, he remained in the drawing-office until August, 1850, when he became manager of the works at Orchard Wharf, Blackwall. Two years later he was admitted as a partner.

The firm of Miller, Ravenhill & Co. had a long established reputation as makers of marine-engines, among its clients being the Peninsular and Oriental Steam Navigation Company, the Royal West India Mail Packet Company, the French, Russian, and Sardinian Governments, and finally the British Admiralty. Soon after he became a member of the firm, Mr. Ravenhill was called upon to bear a large share of the pressure of business consequent on the numerous orders arising out of the Crimean War. He carried out large contracts for the Admiralty, and subsequently took an active interest in the introduction of the screw-propeller into the British and foreign navies.

After many years good work as principal acting partner in the firm Mr. Ravenhill retired in 1874. He did not, however, entirely abandon active work, as for some time he served as an Engineer Assessor to the Wreck Commissioners Court of the Admiralty and

---

[1] Minutes of Proceedings Inst. C.E., vol. xx. p. 149.
[2] *Ibid*, vol. lxxxix. p. 495.

to the Local Marine Board of London, and also as a member of the Thames Conservancy Board. He was a Member of Council of the Institution of Naval Architects, to which he contributed a Paper "Twenty Minutes with our Commercial Marine Steam Fleet in 1877."[1] In 1879 he read before the Royal United Service Institution a Paper "On the latest Improvements in Marine Engines and Boilers."[2] Mr. Ravenhill was elected a Member of the Civil Engineers on the 7th of February, 1865. Although he never contributed a Paper, he always took great interest in the proceedings, was a frequent attendant at the meetings, and more than once gave valuable information in the course of discussions, notably those on Ocean Steam Navigation[3] and on the progress of steam shipping.[4] Mr. Ravenhill died at his residence, Delaford, Iver, Bucks, on the 28th of December, 1894, from exhaustion following a severe attack of bronchitis.

JOSEPH FRANK STRONG, born on the 24th of May, 1826, was educated at Sunderland and in Germany. After serving a pupilage to his father at the Birtley Ironworks, Durham, he was engaged for the late Mr. C. H. Wild for three years on the contract drawings for the Chester and Holyhead Railway, and on the inspection of the works. He was then in charge of the drawing-office, and subsequently assistant manager, at Messrs. Ransomes and Sims, Orwell Works, Ipswich, where he remained five years.

In 1854 Mr. Strong entered the service of the East Indian Railway Company. After being in charge of the line at Raneegunge for twelve months, he assisted the late Mr. George Sibley[5] on the works of the bridge over the river More in the Beerbhoom District. He then carried out surveys in the Jubbulpore District, and in 1859 was placed in charge of the foundations of the bridge over the Jumna at Allahabad, the then largest railway bridge in the world. In 1862 he was in England on sick leave, and on returning to India in the following year was placed in charge of the Cawnpore District. That post he held until the autumn of 1871 when the East Indian Railway Company, compelled to reduce its staff, dispensed with his services.

Mr. Strong returned from India in 1872. In the hope of

---

[1] Trans. Inst. Naval Architects, vol. xviii. p. 280.
[2] Journal Royal United Service Institution, vol. xxiii. p. 598.
[3] Minutes of Proceedings Inst. C.E., vol. xxix. p. 168.
[4] *Ibid*, vol. li. p. 51. [5] *Ibid*, vol. cviii. p. 409.

increasing his income he unfortunately made some injudicious investments which, turning out badly, left him in greatly reduced circumstances. Added to this his efforts to obtain employment proved futile, and ill-health, which after a few years became chronic, soon rendered him unable to accept work had it offered itself. A spinal affection developed into paralysis and for years he lived in retirement on the south coast, nursed and tended by a devoted wife. The end came on the 5th of January, 1895. Mr. Strong was elected a Member on the 2nd of December, 1862.

JAMES PAGE SYMES, born on the 22nd of October, 1842, commenced his engineering career as a pupil of the late Mr. Edward Hayes of Stony Stratford, Bucks. After the expiration of his pupilage he spent two years in the running-sheds of the London and North Western Railway Company at Wolverton, and was then, from 1863 to 1865, an assistant to Messrs. James Simpson and Company, of the Grosvenor Works, Pimlico, for whom he was engaged on extensions of the Lambeth Waterworks at Thames Ditton and at Brixton Hill, and also on the Folkestone and the Bristol Waterworks. Mr. Symes was next, from 1865 to 1871, chief assistant to Messrs. Richard Moreland and Son of Old Street, St. Luke's, for whom he was occupied on the extension of the Eastbourne Waterworks, on reclamation works in Essex, on the fire-proof construction of the Midland Hotel at St. Pancras, and on the design and construction of hydraulic machinery for the Chatham Dockyard Extension. He was then for two years manager to Messrs. H. J. H. King and Co. of Glasgow.

In 1873 Mr. Symes entered into partnership with Mr. N. P. Edwards, under the style of Edwards and Symes, at Millwall, as engineers and shipbuilders. The venture proved successful, the firm during the following twenty years turning out upwards of three hundred vessels of all descriptions, two-thirds of which had machinery fitted into them. His career, however, was prematurely cut short. While on an official trial trip he took cold, which developed into pleurisy and pneumonia, and after an illness of only seven days he expired on the 25th of January, 1895, in the fifty-third year of his age.

Mr. Symes was an able engineer and a man of good business capacity, straightforward and upright in all his dealings. He was elected an Associate on the 29th of May, 1877, and was

transferred to the class of Member on the 6th of May, 1879. Not long before his death he took part in the discussion upon Mr. Durston's Paper on "The Machinery of War-Ships."[1]

WILLIAM VAWDREY, second son of the late Rev. A. A. Vawdrey, for many years Vicar of St. Agnes, Cornwall, was born at St. Day Vicarage on the 17th of April, 1840. When quite a youth he was sent as a student to Messrs. Harvey and Company's Foundry at Hayle, where he remained seven years. He was then employed in erecting pumping- and winding-engines for Messrs. Eustace and Son and other owners. In 1865, after passing the requisite examination, he entered the Royal Navy, but soon afterwards retiring from the service he was appointed assistant engineer to the South Staffordshire Waterworks under Mr. J. R. McClean.[2] Two years later he assumed full charge of the works and remained with the company up to his death on the 2nd of January, 1895.

During these 30 years of service Mr. Vawdrey proved himself a most able and energetic promoter of the company's welfare. At Lichfield he erected a 60-inch cylinder Cornish engine. At Hednesford and Huntington, in the Cannock Chase District, he selected sites and sank two large wells, with extensive additional boreholes and heading, erecting there two 65-inch cylinder Cornish engines. At Woodgreen and Wednesbury he put up two 65-inch Cornish engines. At Fradley, near Lichfield, he sank a large well with a 12-inch borehole, and erected one horizontal compound-engine made by Messrs. Hathorn, Davey and Company of Leeds. At Shenstone, near Lichfield, another large well was sunk and a horizontal compound-engine erected. At Kingswinford near Stanbridge, two 24-inch boreholes were carried down to a depth of 280 feet, and an excellent supply of water was obtained at this station, at which one of Messrs. Hathorn, Davey and Co.'s compound-engines was erected. At Aldridge, near Walsall, a large well was sunk and a vertical compound-engine by Harvey and Co. erected. All these works proved eminently successful and provided a magnificent supply of pure water. A large impounding reservoir was formed at Hanch, near Lichfield, and a service reservoir at Hednesford. At Burton-on-Trent and at Sedgley

---

[1] Minutes of Proceedings Inst. C.E., vol. cxix. p. 71.
[2] *Ibid*, vol. xxxviii. p. 287.

covered service reservoirs were constructed, the former with a capacity of 4,500,000 gallons. Another open service reservoir of about 4,000,000 gallons capacity was made at Rowley Regis. Many miles of pumping- and distribution-mains were laid in connection with these additional works, which were all carried out from the plans and specifications of Mr. Vawdrey, who was scarcely ever absent except for a brief holiday in the autumn of each year. Such lives of devoted service deserve more than a passing notice, and those who knew Mr. Vawdrey best—his own workmen and clerks—bear ungrudging testimony to his urbanity, kindness of heart and strict integrity. He was elected an Associate on the 6th of March, 1866, and was transferred to the class of Member on the 6th of January, 1874.

JOHN EVELYN WILLIAMS, born on the 6th of January, 1845, commenced his engineering career at the age of fourteen when he entered the drawing-office of the Mersey Dock Estate at Liverpool. He soon proved himself to be diligent in seeking information, hardworking and trustworthy, and remained in the service of the Dock Estate until May, 1865, when he was appointed assistant to the engineer of the Bristol Docks. At the close of the following year he became chief assistant to Mr. R. A. Marillier, Engineer to the Hull Dock Company, under whom he remained until the end of 1871. In the following June Mr. Williams was appointed Resident Engineer on the Whitehaven Dock and Harbour improvement works, under Sir James Brunlees.[1] For five years he remained in charge of those works, the nature and extent of which were fully described in a Paper he presented to the Institution in 1878.[2] For that Paper he was awarded a Telford Premium.

At the end of 1877 Mr. Williams obtained the responsible post of surveyor to the Witham Drainage Commissioners. It should be explained that the term "Surveyor" was the official name by which the officers of many of the Lincolnshire Trusts were known in the days before "Engineers" were appointed. The duties of the Witham surveyor consist in the general charge of the drains, sluices, bridges and other works belonging to the drainage system and in the collection of the taxes. The outfall and other work

[1] Minutes of Proceedings Inst. C.E., vol. cxi. p. 367.
[2] *Ibid*, vol. lv. p. 36.

was considered as beyond the ordinary duties, and for such works Mr. Williams was engaged and remunerated as an engineer. At the time of his appointment there had been a succession of wet seasons, and the Fenland forming the watershed of the Witham had suffered very much from imperfect drainage, owing to the unsatisfactory condition of the outfall. Sir John Hawkshaw[1] had recently been engaged by the landowners of the district to report on the matter, and he had previously, when consulted by the Drainage Commissioners, strongly urged the necessity of improving the outfall by making a new cut for the river. The scheme presented by him involved, however, the expenditure of so large a sum that it was not considered desirable to carry it out. Mr. Williams, therefore, soon after his appointment, was instructed to report on the subject. He strongly advised the improvement of the outfall, either by means of the scheme recommended by Sir John Hawkshaw or by a less costly plan of training and deepening the existing outfall.

In 1879 the Witham Commissioners, in conjunction with the Black Sluice Drainage Commissioners and the Boston Harbour Trust, decided to proceed, and the scheme recommended by Sir John Hawkshaw was carried out under the direction and supervision of Mr. Williams as Acting Engineer. The works were fully described by him in a Paper[2] read before the Institution in November, 1888. He also carried out extensive works for improving the drainage in his own district, including the construction of an additional opening to the outfall sluice of the Witham and the enlargement of the waterway; an additional opening to Hobhole Sluice; a new cut and sluice for the outfall of the Steeping river, part of the East Fen drainage system; and numerous other works, including new pumping stations at Greetwell and Gayton, necessary to put the whole of the Witham drainage system in a more satisfactory condition.

Mr. Williams retired from the service of the Witham Commissioners in 1894 and removed to London, where he started practice as a consulting engineer. For some time, however, he had suffered from chronic disease of the kidneys, a severe attack proving fatal on the 20th of January, 1895. In addition to the Papers referred to above, Mr. Williams was the author of a pamphlet entitled "The Steamship: its Strength and Propeller,"[3]

---

[1] Minutes of Proceedings Inst. C.E., vol. cvi. p. 321.
[2] *Ibid*, vol. xcv. p. 78.
[3] Library Inst. C.E., Tracts 8vo, vol. 254.

and of several reports, many of which may be found in the Library of the Institution. He was elected an Associate on the 7th of March, 1871, and was transferred to the class of Member on the 27th of November, 1877.

GEORGE STEPHENSON CAMPBELL, son of Mr. James Campbell, who was for many years an assistant to George Stephenson, was born on the 21st of May, 1848. The great engineer, after whom he was named, was to have been his godfather, but was ill and unable to attend the ceremony. Robert Stephenson, however, stood proxy.

In April, 1866, Mr. Campbell entered the service of the Staveley Coal and Iron Company. For eight years he acted as an assistant, and was then appointed chief surveyor of underground work, with part supervision of new works in connection with the collieries. In November, 1876, he was placed in charge of the works of the Halkyn Mines District Drainage Company. His duties consisted in superintending, amongst other things, the repair of a mile of heading with brickwork and cast-iron nibbing, the sinking of a shaft 220 yards deep, and the driving—by machine-drills worked by compressed-air—of a level 8 feet square through mountain limestone for the purpose of draining the lead mines of the district. From 1881 to 1884 he was employed by Mr. W. H. Barlow to take the measurements, both for the Company and the contractors, in connection with the Belsize Tunnel works. He was then engaged from 1884 to 1888 in Northumberland, for the contractors, on the construction of the Alnwick and Cornhill Railway.

Mr. Campbell's next appointment was that of an engineer on the Great Southern Railway of Spain on the section from Murcia to Granada. In December, 1893, he sailed for the United States to take up the post of Assistant Manager to the Netherlands Phosphate Mines in Florida. There he unfortunately contracted an illness, which ended fatally on the 7th of October, 1894. Mr. Campbell was elected an Associate Member on the 2nd of March, 1880.

sluices, br

and in the c

[1] M.

[2] *Ibid.*

JOHN DUNN FERGUSON, born on the 29th of February, 1864, was apprenticed in 1881 for five years to Mr. Wm. Robertson Copland, of Glasgow, with whom he subsequently remained for eight months as an assistant. During that period he was engaged in the design and construction of many important undertakings, among which may be mentioned works for the water-supply of Girvan, Kinross, Dumbarton, Duntocher and Dalmuir, Gourock, and Falkirk; the drainage of Dumbarton, the Barony of Glasgow, Falkirk, Helensburgh and Largs; Shandon Pier; and repairs to the basin of Leven Shipbuilding Yard.

In January, 1887, Mr. Ferguson entered the service of Messrs. Lobnitz and Co., the engineers and shipbuilders of Renfrew. After being employed in the shipyard of that firm for twelve months he was sent to London to take charge of the erection of machinery. From April, 1890, to September, 1891, he was engaged for Messrs. Bateman, Parsons and Bateman in superintending the laying of iron pipes for the water-supply of Buenos Ayres. He was then employed by the Argentine Commission of Health to superintend generally the execution of the works in Buenos Ayres. Mr. Ferguson's career, however, was prematurely cut short. He was attacked by illness on his way home from Argentina and died in London on the 14th of April, 1894. He was elected an Associate Member on the 13th of January, 1891.

EDWIN DAVENPORT LATHAM, youngest son of the late Mr. George Latham, architect, of Nantwich, was born on the 3rd of January, 1843. After being educated at the Nantwich Grammar School and receiving some training in his father's office, he acted as Assistant Town Surveyor of Nantwich from 1862 to 1866, during which time he superintended the construction of an auxiliary impounding-reservoir for the waterworks. In 1866 he was appointed Engineer and Surveyor to the Corporation of Bideford, where for three years he was engaged in constructing river embankments and sewerage works. His connection with Middlesbrough, where he spent the greater part of his life, commenced in 1869, when he was appointed Engineer and Surveyor of that borough.

In that capacity Mr. Latham carried out many public improvements, including main drainage works, fever hospitals, public baths, and the reconstruction of nearly three hundred streets. In

1879 he undertook the management of the gasworks, and during the eleven years they were under his charge the output was doubled and the price was reduced to 2*s.* per 1,000 cubic feet. He designed and executed steam-ferry works on the River Tees, and in 1875 and 1876 he reported and gave evidence before Parliamentary Committees on every town and village discharging sewage into the river, both above and below the point whence the towns of Middlesbrough, Stockton and Darlington derive their water-supply. This was in connection with an agitation which resulted in the corporations of Stockton and Middlesbrough becoming the owners of the waterworks by compulsory purchase.

In 1892 Mr. Latham suffered from an attack of congestion of the lungs, which left him in a weak state of health. His death, which took place on the 21st of November, 1894, was due to bronchitis coupled with weak action of the heart. Mr. Latham was elected an Associate Member on the 4th of February, 1879.

KARL EMIL NABHOLZ was born at Reutlingen, Germany, on the 3rd of May, 1856. His father, who was the proprietor of a flax-spinning mill, failing shortly afterwards, little Karl was taken with the family to Zürich, where he was educated at one of the well-known industrial schools of that city. At sixteen years of age he obtained, through a brother in England, a post as a draughtsman and clerk at the Hexthorpe Railway Wagon and Ironworks, Doncaster. In 1874 he removed to Barrow-in-Furness as draughtsman and foreman of the foundry at the Barrow Railway Rolling-Stock and Steelworks, where he remained three years. He was then for twelve months Assistant Bridgeyard Manager, under his brother, at the Skerne Ironworks, Darlington, and in 1878 became an assistant in the Engineering Department of Messrs. Kennan and Sons of Dublin, where he was employed on iron-bridge building and general machinery work.

In February, 1882, Mr. Nabholz entered the service of the Commissioners of Irish Lights as a draughtsman, under Mr. William Douglass, and was engaged for some years on general lighthouse work. In June, 1891, he was promoted to the post of Assistant Engineer, which he held until his death from typhoid fever on the 24th of May, 1894. Mr. Nabholz was an excellent draughtsman and designer, had a thorough knowledge of his work, was a good linguist and possessed considerable tact in the manage

ment of those under his charge, while his kind and courteous manner made him universally popular. He was elected an Associate Member on the 4th of May, 1886.

HARRY WREATHALL, son of Mr. Matthew Wreathall of the Manor House, Greenhill, Harrow, was born on the 30th of March, 1866. After being educated at a private school at Worthing, he was articled, in April, 1883, to Mr. John Wilson, Engineer-in-chief of the Great Eastern Railway, for three years. During that time he was employed on general office work and on the preparation of drawings for new lines. On the expiration of his pupilage in April, 1886, he was engaged for two years as an assistant engineer on the construction of the Great Eastern Railway Company's new line from Shenfield to Southend, and on the Bury and Kennett widening.

In January, 1889, Mr. Wreathall obtained an appointment as an assistant engineer on the Argentine North Eastern Railway, and on his arrival in that country was placed in charge of the construction of a section of 120 miles, 88 miles of which were duly opened to the public. He returned from Argentina in January, 1893, and not being in good health determined to rest for a few months. In April of the following year he was appointed an assistant engineer to the Willesden Local Board, and he held that post at the time of his death, which was caused by an epileptic fit on the 5th of September, 1894. Mr. Wreathall was elected an Associate Member on the 1st of March, 1892.

⁂ The following deaths have also been made known since the 26th of February, 1895:—

Members.

CRICHTON, ROBERT; *born* 21 December, 1847; *died* 17 January, 1895. (*Blood poisoning, the result of an accident.*)

ECKERSLEY, WILLIAM ALFRED; *born* 25 January, 1856; *died* 23 April, 1895. (*Yellow fever.*)

GILES, ALFRED (*Past-President*); *born* 1816; *died* 3 March, 1895. (*Jaundice.*)

MITCHELL, JOSEPH; *born* 7 September, 1840; *died* 18 April, 1895.

NAPIER, JAMES MURDOCH; *born* 26 July, 1823; *died* 23 March, 1895. (*Throat affection.*)

PRICE, JAMES, M.A.I.; *born* 18 January, 1831; *died* 4 April, 1895. (*Pneumonia following influenza.*)

SMITH, JOHN CHALLONER; *born* 1828; *died* 13 March, 1895.

Associate Members.

COOKE, ALFRED THOMAS; *born* 14 September, 1819; *died* 15 April, 1895. (*Paralysis and cerebral hæmorrhage.*)

JARVIS, EDWARD WORRELL.

JORGENSEN, FREDERICK; *born* 9 August, 1831; *died* February, 1895. (*Paralysis of the brain.*)

OXLEY, JAMES ABBOTT; *born* 3 July, 1852; *died* 21 March, 1895. (*Sunstroke.*)

PEAKE, CHARLES EDWARD; *born* 28 July, 1856; *died* 3 April, 1895. (*Paralysis.*)

PEARSE, WILLIAM MONRO; *born* 10 March, 1840; *died* 26 February, 1895. (*Blood poisoning.*)

STRACHAN, JOHN HENRY; *born* 12 February, 1864; *died* 6 March, 1895. (*Pneumonia following influenza.*)

Associate.

GREENER, JOHN HENRY; *born* 1829; *died* 7 April, 1895.

SCHAFHAEUTL, Dr. KARL EMIL VON; *died* 25 February, 1890, *aged* 88.

STOTHERD, Major-General RICHARD HUGH, late R.E., C.B.; *born* 1828; *died* 1 May, 1895. (*Heart disease.*)

Information as to the professional career and personal characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 9 *May*, 1895.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

The Elastic Properties of Cements and Mortars.

By Prof. E. Hartig.

(Der Civilingenieur, 1894, p. 717.)

The Author refers to the expression of surprise by Sir Benjamin Baker[1] that his (the Author's) earlier experiments[2] showed that the modulus of elasticity of a sand and cement mortar was higher than that of neat cement. It appeared therefore worth while to make some further experiments. Three specimens, 3·2 inches long and 1·66 square inch sectional area, were prepared of neat cement, and three specimens of 3 parts sand and 1 part cement. After being left a day in moist air they were placed in water, and only taken out during the duration of the experiments.

The variation of the modulus of elasticity with age can be represented by the formula—

$$E_o = b - \frac{m}{a + t},$$

t being the age in days, E_o the corresponding modulus of elasticity at zero stress, a, b and m constants which can be determined from three sets of observations.

1. *Portland Cement, made by Mr. E. Tillgner, Schimischow.*—The experimental results on neat cement can be represented by the formula—

$$E_o = \left(3{\cdot}400 - \frac{108{\cdot}3}{47{\cdot}4 + t}\right) 10^5 \quad . \quad . \quad . \quad . \quad (1)$$

E_o being given in atmospheres, or kilograms per square centimetre.

The specimens 3 parts sand and 1 cement give the result—

$$E_o = \left(5{\cdot}627 - \frac{917{\cdot}6}{320 + t}\right) 10^5 \quad . \quad . \quad . \quad (2)$$

From (1) and (2) the modulus of elasticity of the mortar is greater than that of the neat cement; the ratio of the two modulii at ages of 50, 100, 200, 300 and 400 days being 1·38, 1·29, 1·30, 1·34 and 1·38 respectively. That is, on the average, the elastic

[1] Minutes of Proceedings Inst. C.E., vol. cxv. p. 106.
[2] *Ibid*, vol. cxv. p. 409.

modulus of the mortar is 36 per cent. greater than that of neat cement.

2. *Portland Cement, made by R. Guthmann and Jeserich, Rüdersdorf.*—For neat cement—

$$E_o = \left(4 \cdot 556 - \frac{183 \cdot 5}{79 \cdot 1 + t}\right) 10^5 \quad . \quad . \quad . \quad (3)$$

and for mortar 3 parts sand and 1 part cement—

$$E_o = \left(5 \cdot 35 - \frac{421}{200 + t}\right) 10^5 \quad . \quad . \quad . \quad (4)$$

With this cement, the modulus of elasticity of the mortar is therefore on the average 12 per cent. greater than that of the neat cement.

3. *Brunswick Slag Cement.*—For neat cement—

$$E_o = \left(2 \cdot 676 - \frac{150 \cdot 7}{77 \cdot 2 + t}\right) 10^5 \quad . \quad . \quad . \quad (5)$$

The results of the experiments on mortar of 3 parts sand and 1 part cement are too irregular to be represented by a simple algebraic curve; but the values of E_o are all considerably higher than the corresponding values for neat cement.[1]

A. S.

Experiments with Cement and Trass Mortars hardening in Fresh- or Sea-water. By N. M. Koning and L. Bienfort.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1893–94, p. 110.)

The experiments were made with mixtures of sharp clean river-sand, Portland cement of "Josson" and hydraulic lime in different quantities, as, 1 cement, 3 sand; 1 cement, 4 sand; 1 cement, 3 sand, 0·5 hydraulic lime; 1 cement, 4 sand, 0·5 hydraulic lime; and one trass Herfeldt mark, 1·4 sand and 0·6 hydraulic lime. Of all these different mixtures one-third was made with fresh water and hardened in fresh water, one-third made with fresh water and hardened in sea-water, and the rest both made and hardened in sea-water. After 5, 28, and 182 days of each different description, six blocks were submitted to stress and six to crushing, and of each similar six samples, the highest and lowest readings eliminated. From these experiments it would appear that the mixture and hardening in fresh-water give the best results, particularly with the mixtures of trass. The Paper contains two tabular returns and diagrams. H. S.

---

[1] Minutes of Proceedings Inst. C.E., vol. cxv. p. 109, Sir B. Baker suggested that the quality of the sand had great influence on the modulus.—Sec. Inst. C.E.

Action of the Sand and Water of the Sahara on Cements.

By JULES PERRET.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxix., 1894, p. 654.)

The Author found in 1893 that some mortar and cement at Tougourt, prepared in 1864 with sand and water from that locality, was a good deal disintegrated, especially where it came in contact with the underground water. A series of experiments led to the conclusion that this action is due to the presence of calcium-sulphate, of which the sand sometimes contains as much as 50 per cent. For the same reason the water of the Sahara was found to produce a more rapid decomposition of the mortar than water from the Mediterranean.

He recommends, therefore, great care in the selection of the sand, as its composition has been shown to be very variable.

G. J. B.

Tests of Limes and Mortars. By H. BURCHARTZ.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1894, p. 156.)

This Paper contains the results of investigations made during the years 1885–93 in the testing-station for building-materials. The tests were made to determine the general properties of the materials sent in for examination, and the strengths in tension and compression at different ages and with different methods of hardening. Fifty-three different materials are reported upon, the results being given in tabular form. The variation in strength is very great, but since the materials come from different sources, and are intended for quite different purposes, the difference in the results is not to be wondered at.

As an example of the influence of age and different mixtures of sand on the strength of mortar, a mortar composed of one volume of lime to two of normal sand compared with a mortar of one part of the same lime, one part trass, and two of normal sand, shows a diminution of strength of 1001·8 per cent., 868 per cent., 802 per cent., after 28, 60, and 90 days respectively.

A. S.

On the Protection of Ironwork against Fire. By — KAPAUN.

(Zeitschrift des österreichischen Ingenieur und Architekten Vereines, 1894, p. 381.)

Under the supervision of the city surveyor experiments have recently been made at Vienna with the object of testing the efficiency of protection of ironwork against fire, and incidentally

to determine the relative fire-resisting properties of various building materials.

A brick chamber, 12 feet 1½ inch by 8 feet 1 inch, and 11 feet 6 inches high, was constructed, the walls being lined with various building-stones and other materials. In the centre of this chamber was erected an iron column, consisting of two channel-bars, 5½ inches by 2⅜ inches, back to back, with a clear space between of 2½ inches, cross-braced with small lattice bars. This column, forming a hollow central space in which were placed thirteen test-bars of different alloys, melting at various points between 150° F. and 1,650° F., was inclosed in brickwork in mortar, unpointed, forming a pier 1 foot 6½ inches square, the brick casing having a thickness of 6 inches. The building was covered with a fire-proof roof, formed of tiles on wrought-iron joists, and levelled up in concrete, and two flues were built in and upon this floor. The column was loaded to the extent of 14·4 tons by means of a lever with fulcrum over the centre of the column, the short arm being held down by anchor-bolts through the back wall, and the long arm loaded to the requisite extent, which was equivalent to a strain of 3¼ tons per square inch, *i.e.*, about the breaking weight of wrought-iron at 1,290° F., or of Bessemer steel at cherry-red heat.

The fuel was piled equally all over the floor to a depth of about 3 feet, and the firing was maintained at its full intensity for two hours and a half, and then kept on one side of the building to test the effect of unequal heat. The fire brigade then commenced playing upon the roof and inside walls and column; but the heat to be subdued was so intense that the interior of the chamber could not be examined until the following day.

The corners of the brick pier were crumbled to the extent of 1¼ inch to 1½ inch, and several roof-tiles were split. The brick-work was wet through. Generally speaking, the walls remained vertical, and the iron column was quite uninjured. The test-bar fusing at the lowest temperature of the series (150° F.) was the only one in which there was any appearance of partial melting, so that it was evident that the brick casing was amply sufficient for the protection of the column. The brickwork surface in general stood very well, but most of the stones were honeycombed or granulated, and plaster-surface afforded no resistance sufficient to be taken into consideration.

P. W. B.

On the Flexure of Columns. By Félix Jasinski.

(Annales des Ponts et Chaussées, September, 1894, p. 233.)

The Author gives a brief account of the theoretical treatment by previous writers of the strength of an elastic column, subject to longitudinal forces applied at the ends of its axis, and says that this theory rests now on an absolutely solid base. He proceeds to apply a similar treatment to other cases.

The case of a column whose ends are free, and which is subject to axial forces only, is called the "principal case"; and he expresses the strength of any other column by the ratio of its length to the length of a column in the "principal case" which will support the same load without flexure. The cases considered are those in which the load, instead of being applied at the ends of the column, is applied continuously along the axis, either uniformly distributed or varying according to a given law. He also considers the effect of longitudinal loads combined with transverse forces proportional to the transverse displacement produced by a small flexure of the column.

This last case is approximately that of the compression-bars in a lattice girder in which the lattice bars are not far apart, and are riveted at every intersection. He finds the coefficient of length for such a compression-bar to be—

$$\frac{1}{\sqrt{1 + \frac{I_1}{I} + \frac{Q\,l^2}{E\,I\,\pi^2}}},$$

where I and I_1 are the moments of inertia of cross-sections of the compression-bar and of the tension-bars crossing it respectively. Q is the stress in each tension-bar, and l the common length of the two sets of lattice bars.

Another chapter is devoted to a review of modern experiments, including those of Considère, Strobel, Bauschinger and Tetmajer. The conclusion arrived at is that the dangerous load (*i.e.*, the load at which flexure commences) is correctly given by a formula of Euler's form, when the length of the column exceeds a certain multiple of the radius of gyration; and that for shorter columns the dangerous load is expressed by a formula of the form $a - b\left(\frac{l}{r}\right)$, where a and b are constants, r is the radius of gyration and l the length. The change from one formula to the other is made when $\frac{l}{r} = 114 \cdot 7$ for puddled iron, and when $\frac{l}{r} = 110 \cdot 1$ for mild steel.

A Table is given of the dangerous load in tons per square centimetre for values of $\frac{l}{r}$ from 20 to 200, calculated from formulas which in tons per square inch become—

$$12 \cdot 735 \left(\frac{r}{l}\right)^2 \text{ and } 21 \cdot 87 - 0 \cdot 1063 \left(\frac{l}{r}\right) \text{ for puddled iron.}$$

$$13 \cdot 73 \left(\frac{r}{l}\right)^2 \text{ and } 21 \cdot 85 - 0 \cdot 0957 \left(\frac{l}{r}\right) \text{ for mild steel.}$$

The Author considers that eccentricity in the application of the load, accidental initial curvature, and want of homogeneity, within

the limits of ordinary manufacture and workmanship, do not impair the strength of a column so far as to make the formulas above quoted inapplicable. It is desirable, however, that the greatest radius of the cross-section of the column, measured from the centre of gravity of the area, should not exceed $2 \cdot 75\ r$ (r being the radius of gyration), as otherwise the effect of initial curvature might become serious. In support of these propositions a mathematical investigation is given in the Appendix.

In regard to columns forming parts of a riveted framed structure, he considers that such columns should, as a measure of precaution, be treated as having hinged ends, seeing that it is impossible to define the degree to which the ends are fixed.

The last chapter of the Paper is devoted to the practical application of the methods and formulas to the design of girder bridges; and a special study is made of the lateral stability of through bridges without transverse bracing to the upper booms. The results of this study are confirmed by applying them to two instances of bridges of that kind which failed by the yielding of the upper booms.

C. F. F.

Börnstein's Wind-Measurer. By — Buchholtz.

(Verhandlungen des Vereins für Eisenbahnkunde, 1894, p. 98.)

In a Paper describing several apparatuses for measuring the pressure of wind, the Author states that the one which gives the most accurate results is that of Professor Börnstein. This apparatus consists of a light hollow ball fixed on the top of an axle, the bottom end of which rests in a ball-and-socket joint. An arm is fixed to the joint, which extends below to the measurement room, and by means of a good transport mechanism registers the wind-pressure on a strip of paper moved by clockwork. In addition a side-lever is provided which by means of balance weights will denote the absolute pressure at any required time.

The Author states that most appliances for obtaining the wind-pressure register only the speed, from which the pressure is calculated, the results obtained giving varying amounts, according to the formula used; but with Börnstein's apparatus the pressure is registered directly on the paper, and it also registers with great accuracy the pressure of single gusts of wind. The chief disadvantage of this apparatus lies in the fact that the same instrument will not register with sufficient accuracy a pressure of a few grams and one of several kilograms, and it is thus necessary to have two or more appliances at the same place.

The Paper is accompanied by a Plate containing sketches of Börnstein's apparatus and several other wind-measurers.

J. A. T.

The Instruments employed by the Government Works Department in the Netherlands to investigate the Strains in Iron Bridges.

By J. Schroeder van der Kolk.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1893–94, p. 170.)

According to the agreement between the Government and the Railway Companies in the Netherlands, all the bridges of large spans must be periodically tested under Government supervision. Since this system has been in force these operations have brought to light many and often unsuspected facts, such as the flexures and strains set up by the rigid joining of the different members of a main girder and the lateral deflections and warpings in these, by the bending under a load of the cross-girders. The information so obtained led to the latest method of fixing cross girders on the longitudinal beams.

To conduct these investigations with due care and precision, eighty-five Manet instruments were obtained, as also six with micrometer screws, and two by Fränkel. Although the object is to obtain information as to strains under varying loads, the instruments named do not directly indicate the force acting on any part of the structure, but only the elongation or compression of such parts, from which again the actual force causing transformation is calculated. The operations require a large staff of trained assistants, and the instruments careful adjustment and manipulation. In principle these instruments consist of two metal plates, fixed rigidly some distance apart, usually 1 metre, on the member to be observed. For investigating elongations the two plates are joined by means of a steel tape; for compressions by a steel rod, by means of which an indicator is moved, recording the transformation on the member between the two clamp-plates. The instruments are described in detail and large scale drawings explain their arrangement. As a result also of a great many tests, it is now, amongst other matters, established without doubt that in large structures the factor of safety is very much less than five or six, on which calculations are based. There is no cause for anxiety, however, as long as any member is not strained beyond the modulus of elasticity. These tests give no information as to strains or stresses set up in a structure by its own weight.

H. S.

A Horizontal and Vertical Vibration-recorder.

By Prof. W. Fränkel.

(Der Civilingenieur, 1894, p. 677.)

The horizontal vibration-recorder shows some important improvements on the earlier form.[1]

The principle underlying the construction of the vertical vibration-recorder, as in the horizontal vibration-recorder, is the application of a heavy weight, hung in such a manner that it will make very long oscillations, to which the more rapid oscillations of the structure on which it is placed can be referred. The heavy weight is supported by a spiral spring, which must be very long if slow oscillations are desired. An important improvement is effected by hanging the heavy weight, not directly on the spring, but at the end of a lever; this is done in the instrument described.

Diagrams given by the instrument when placed on the bridge over the "Black Elster" at Elsterwerda are reproduced in the Paper. In this bridge it is concluded from the vibration diagrams that not only do horizontal vibrations take place when the bridge is being used, but also slow horizontal bending. At a speed of 34 miles per hour the period of impact of the locomotive wheels on the rails coincides with the period of vibration of the bridge, and dangerous effects might be produced at this speed. From the greatest observed amplitude, it is concluded that the stresses are increased 9·5 per cent. in consequence of the vibration.

The Paper is accompanied by two sheets of drawings and reproductions of curves from the instrument.

A. S.

Bridge carrying the Girdle Railway over the Ourcq Canal at Paris. By A. Hauet.

(Revue générale des Chemins de fer, November, 1894, p. 231.)

The first bridge over the Ourcq Canal was erected in 1852, when the "Girdle" Railway was constructed, and consisted of two side girders and an intermediate girder; the girders were continuous and rested on a masonry pier midway between two quay-piers. The clear skew opening between each quay-pier and the centre pier was 63 feet. The girders were plate girders, the depth of the side girders being 4·59 feet, and that of the centre girder 5·42 feet. The railway was carried by cross girders and rail-bearers. On the 25th of February, 1891, immediately after a

[1] Der Civilingenieur, 1894, p. 223, and Minutes of Proceedings Inst. C.E., vol. cxviii. p. 467.

goods train had passed over the bridge, a rent was observed in the web of the centre girder, at the junction with the vertical web of the lower angle-bars, the rivets fixing the cross-girders being sheared off, and all traffic had necessarily to be stopped at once. It was found that the ironwork had sustained very little deterioration through oxidation, but the sectional areas were not in proportion to the always increasing rolling-loads, and to the conditions exacted by the new ministerial circular. On the 1st of March a temporary wooden foot-bridge was opened to enable passengers to walk between the two sides of the canal. The old bridge was then demolished, and a temporary single-line one was erected, of the "Marcille" type, and opened on the 14th of March. A second temporary bridge, of the same type, was then erected.

The "Marcille" bridge consists of plate girders formed of pieces of various lengths corresponding to determined spans. In the present case two portions of bridges of 98 feet span were put together to form a single girder resting very nearly at its centre on the pier. These spans were composed of pieces having the following lengths for one half of the girder: 8·2, 24·61, 32·81, and 8·2 feet. One of the great advantages of the "Marcille" type consists in the small width from outside to outside of flanges of main girders, which is 6·89 feet. The rail, of Vignoles type, is fixed on to the upper flange with the interception of an iron bedplate. The girders are 4·92 feet in depth, and are braced together at the top and bottom flanges; brackets to form footways can readily be attached at either side, or on both sides.

The new permanent bridge, the erection of which commenced in the following July, consists of two independent bridges, one for each of the two lines of way. There is a gradient of 1 in 120·5 at the bridge, and an angle of skew with the canal of 58° 18′ 35″. The centre pier was done away with, and the abutments were set back on each of the quays to form line with the buildings, the piers at each side of the canal remaining in their previous positions. There were thus three spans, the skew dimensions being respectively 134·12 feet for the main span over the canal, and 37·56 feet for each of the spans over the quays. The main span consists of two lattice girders, spaced at 16·24 feet centre to centre, 19·68 feet in depth, the vertical struts being 10 feet centre to centre. The girders are braced together on the top flanges, and cross girders, 10 feet apart, rest on the bottom flanges, between which are rail-bearers, the flooring consisting of 0·27-inch plates. The calculations were made, conformably to the ministerial circular of August, 1891, according to which the strain allowed is 3·175 tons per square inch. The principal characteristics of the bridge are: first, that the rail-bearers are continuous over the three spans; secondly, the cross-girders and rail-bearers are of the same depth over the three spans; thirdly, the flooring is intimately associated with the resistance and rigidity of the work by careful riveting; fourthly, the flooring is not pierced by any bolts, which has rendered the tightness very nearly perfect;

fifthly, the bearers, on which the girders rest, have a height such that the underside of the flooring, girders, &c., can always be seen.

The following were the weights:

MAIN SPAN OVER CANAL (TWO LINES OF WAY).

	Tons.
Wrought-iron	290·27
Cast-iron	4·28
Steel	2·71
Lead	0·28
	297·54

or $\frac{297 \cdot 54 \text{ tons}}{145 \cdot 02 \text{ feet}} = 2 \cdot 05$ tons per lineal foot-run.

TWO SIDE SPANS.

	Tons.
Wrought-iron	107·54
Cast-iron	5·04
Steel	1·72
Lead	0·27

The contract was let to Messrs. Jolly and Delafoy of Argenteuil at £15 18*s.* 6*d.* per ton.

The Author describes in detail the manner and results of the tests made of the ironwork, both from the old bridge and the new bridge. Three plates and figures in the text accompany the Paper, giving details of both bridges and of the temporary bridge.

J. A. T.

Construction of a New Pivot-Pier with Pneumatic Foundation.

By A. A. H. W. König.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1893–94, p. 133.)

On October 12th, 1890, the swing-bridge on the Amsterdam Ship Canal, in the public road near Velsen, was seriously damaged by a steamer coming up from Ymuiden in a thick mist. The vessel, going full speed, collided with the fender-piles, broke these, and then bearing down on the bridge, at the time opened for navigation, pushed this and the pier over, by nearly a foot, bending and disarranging the pivot and rollers. It being considered unadvisable simply to push the pier back again into a perpendicular position, the construction of a new pier on the same spot was decided on. To accommodate the road-traffic during construction a ferry-punt was provided for wheeled conveyances and one for foot-passengers. The superstructure was then slewed over on to the northern canal bank, and the pier removed chiefly by the employment of dynamite, of which 1,428 cartridges in 182 discharges were used, of a total weight of 119 kilograms.

The old pier was a cylinder 5 metres in diameter, with a foundation 0·80 metre (2 feet 7½ inches) below the canal-bottom. As the new locks at Ymuiden will allow larger vessels to enter than those for which the canal was originally intended, it is expected that the section of the present work will before long have to be enlarged, as well in depth as in width. The new pier required to be constructed accordingly, and the foundation carried down to a greater depth. After careful borings solid sand was found at 21 metres below Amsterdam datum, or 11·50 metres (37 feet 9 inches) below the canal-bottom. This depth required the foundation to be laid by some pneumatic process, and a dome of brickwork for an excavation-chamber was at first thought of, but was abandoned, and the contractors, Messrs. Mortier and Thouvard, of Saumur, France, were allowed to employ their usual method, with an iron air-chamber and one air-shaft. The diameter of the new pier is 8 metres (26 feet 3 inches), and the vertical axis was placed 1·50 metre further northward than that of the old one, so as not to diminish the clear width in the southern opening. On October 6th, 1891, the curb of the air-chamber, weighing in all 13 tons, touched the bottom at 7·26 metres under Amsterdam datum, and the excavation proceeded at the rate of from 20 to 35 metres cube in the twenty-four hours. On the 9th November the lower edge of the air-chamber had sunk to 21·02 metres below Amsterdam datum, when the concrete filling was begun. This consisted of 1 part Portland cement, 2 parts sand and 3 parts broken brick. After the air-chamber was nearly filled, cement mortar was pressed in, the iron air-shaft removed, and the central cavity also filled up. The body of the pier above the air-chamber is built up of brick in cement-mortar. The pivot was replaced in its old position, or eccentrically of the new pier, so as to utilize the existing span. This was then again slewed in its place, and on the 16th of December, 1891, or four months after the reconstruction had been commenced, the bridge was reopened for public use.

The Paper contains several drawings and diagrams.

H. S.

The Illinois and Mississippi Canal. By J. W. Woermann.

(Journal of the Association of Engineering Societies, 1894, p. 613.)

This canal, in connection with the Upper Illinois River and the commodious channel now being constructed by the city of Chicago,[1] will provide a short route from the Upper Mississippi River to Lake Michigan. The canal will reduce the distance from Chicago to Rock Island from 607 miles to 188 miles. It extends from a point 1¾ mile above the town of Hennepin, at the great bend of

[1] Minutes of Proceedings Inst. C.E., vol. cxix. p. 433.

the Illinois River, to the Mississippi, at the mouth of the Rock River, a distance of 77 miles. It reaches its summit level 20 miles from the Illinois River, after ascending 205 feet, by means of twenty-four locks with lifts varying from 3 feet to 10 feet. The summit level is 5 miles long, and it then descends to the Mississippi River, 102 feet, through fourteen locks, with falls of from 5 feet to 12 feet.

The width of the canal at the water line is 80 feet, and the depth 7 feet. The locks are 170 feet long and 35 feet wide, and are built of concrete. The Author describes the method of building in detail.

A. W. B.

The Flood-water Canal of the River Ill at Erstein, near Strassburg. By H. Fecht.

(Zeitschrift für Bauwesen, 1894, p. 369.)

The River Ill rises in the Jura range, in Upper Alsace, and enters the plains at Mulhausen. Its general course thence is practically parallel with the Rhine, and falls into that river about 12½ miles below Strassburg. It receives a large number of tributaries from the Jura and the Vosges mountains, and is subject to considerable floods. From Mulhausen downwards the river may be divided into two sections, viz., the length between Mulhausen and Colmar, and that between Colmar, Erstein, Strassburg and its outfall into the Rhine, the latter length only being navigable. The Mulhausen-Colmar section carries but very little water during the summer, as its tributaries are used for irrigation and general industrial purposes, and, except in times of flood, do not join the Ill until reaching Ladhof, a short distance below Colmar.

The flood-water canal and accompanying works, described by the Author, were carried out for the purpose of restricting the spread of the floods to the valley above the town of Erstein, and diverting the excess into the Rhine flood-area at the Plobsheim weir, about 4⅓ miles from Erstein, instead of permitting it to continue its course, by way of the River Ill, through Strassburg to its outfall into the Rhine, about 10 miles below the city. Many parts of Strassburg and its suburbs were, previous to the construction of the works in question, subject to floods of as much as 3 feet in depth, preventing the proper development of the suburbs, and causing a very unsanitary condition.

This state of affairs is now remedied by the works, carried out between the years 1886 and 1891, the flood-level having been lowered practically to that extent, and an area of 865 acres of land in the vicinity of Strassburg, otherwise suitable for building on, made available for that purpose. The maximum volume of flow through Strassburg in times of flood is now reduced from 14,126 cubic feet per second to 7,946 cubic feet per second.

The various works, which include the regulation of portion of the River Ill, are described in detail, and the Paper is illustrated by a general map and elevations, plans and sections of the principal weirs. The length of the flood-canal from its commencement, where it leaves the Ill at the Börscheidich sluice, to the embankment bounding the Rhine flood-area is 5¼ miles. Of this length about one-half is formed by an entirely new cut, and the remainder by the regulation of the Murgiessen, a branch of the Rhine-Rhone navigation canal, serving Erstein, and of the River Kraft. The new cut is excavated to a depth of from 6 to 6½ feet, with a bed of from 85 to 131 feet in breadth, according to the fall, which amounts to 1 in 1,250 for the first 3½ miles, and 1 in 2,500 for the remainder. There is, as a rule, a cess of 33 feet between the edge of the canal and the foot of the flood embankment, or dam; and the top of this is 2 feet 8 inches above the highest level of the lake formed in times of flood, and which latter is free to spread up the valley, it being only confined between two lines of dams (for a length of about ⅔ mile) near the village of Kraft. At about 1⅓ mile from its commencement the flood-canal runs into the Murgiessen, and is formed by the regulation of that navigation. At about 2¼ miles the flood-canal enters and leaves the Rhine-Rhone navigation canal (close to a lock upon the latter), the level of their water-surfaces being identical. Immediately after this there is a needle-weir and a bridge carrying the main road from Strassburg to Basle. By the flood-dam of the flood-canal on the one hand, and by the dam of the Rhine-Rhone canal upon the other, the whole of the flood-water of the Upper Ill basin is cut off from the lower district, and diverted into the flood-area of the Rhine. The breadth of the top of the dam varies from 10 feet to 20 feet, and the slope on the side next the canal is 2 to 1, and on the outer side 3 to 1.

The main works upon the canal and upon the Ill comprise the following, viz., the Börscheidich weir, at the commencement of the canal, where it leaves the Ill, has seven openings, each 16 feet 5 inches wide, the whole width between the abutments being 138 feet 6 inches.

The weir, &c., across the river at Steinsaudich, about 15 chains below the point where the canal leaves the river, includes a navigation-pass, 16 feet 5 inches wide, a fish-ladder, 3 feet 3 inches wide, a shutter weir of four bays, each 16 feet 5 inches wide, and a 3 feet 10½ inches wide overflow channel; also a shutter weir of two bays, each 16 feet 5 inches wide, for supplying the lead to the Erstein mills, and a small-boat lock on the left bank, 6 feet 7 inches wide and 41 feet long. The whole width of the weir between the abutments is 163 feet 4 inches. The needle-weir at Kraft is 112 feet 2 inches wide, and, in addition, there is a pass for vessels, a fish-ladder, and a lock for small boats. The Plobsheim weir is the largest of these works, and serves to regulate the outfall of the flood-canal water into the Rhine flood-area. It comprises seven shutter-weir openings, each of 13 feet

2 inches breadth, a fish-ladder, 3 feet 3 inches broad, and a small boat lock similar to that at Börscheidich. The piers are 18 feet long, 4 feet 3 inches broad, and 17 feet high. It is constructed so as to be capable of excluding the Rhine floods, should the latter at any time stand at a higher level than the flood-canal water.

The prices of labour and of the principal building materials are given. The total cost of the flood-canal and the works in connection therewith upon the Ill and on the Murgiessen amounted to £52,500.

D. G.

The Proposed Nile Reservoirs. By A. Boulé.

(Le Génie Civil, vol. xxvi., 1894, p. 49 *et seq.*)

The Author of these articles was, with Sir B. Baker, K.C.M.G., and Mr. Torricelli, a member of the Commission appointed by the Egyptian Government to advise on the subject of forming storage reservoirs in the Nile basin. As is well known, the Author dissented from the views taken by his colleagues and presented a separate report. The present articles are intended to explain and defend his opinions on the question.

An historical sketch is given of the proposals made at various times for the formation of storage reservoirs in the Nile basin, and the proceedings of the Commission are briefly described.

His opinion is that the selection of Assouan as the only possible site for a dam arises from the choice of a wrong type of dam, viz. that built of solid masonry, a type which demands exceptional foundations, not to be found elsewhere than at Assouan. He considers that a dam with movable shutters is perfectly feasible and could be built at other sites, where the necessity of submerging ancient monuments would not arise. He considers that the masonry dam proposed by his colleagues would be too far weakened by the openings in it which are necessary to pass the flood-waters of the river, amounting to nearly 500,000 cubic feet per second, and that to strengthen it adequately would involve enormous expenditure.

A further objection to the dam at Assouan which he urges is the very large area which it would cause to be submerged—an area which is at present fertile and populous.

The plan which he recommends is to divide the fall into stages, sites being chosen for the separate weirs with regard to the contours of the valley as well as to their suitability for construction purposes. The fall at each weir might still be considerable compared to that for which movable weirs have hitherto been constructed, and special arrangements would be necessary to meet the considerable head of water to be dealt with, and also to pass over the weirs so large a body of flood-water without damage.

The special arrangements which he recommends are: (1) to make

the shutters lean outwards from the reservoir, with an inclination of 20° or 25°, instead of making them vertical, as usual;[1] this leads to a more secure and less expensive construction of the piers; (2) to divide each shutter by horizontal joints into a series of sections each of which could be separately lifted and lowered;[2] (3) where the fall of water over the weir would be so great as to be a source of danger, and where the pressure on the lower parts of the weir would be excessive, to construct the weir in a series of steps, forming really a series of weirs brought very close together and supported by one set of piers. By this device each shutter would only be exposed to a moderate pressure arising from the difference of level on its two faces. The number of shutters to be moved would be a matter of no consequence because of the very large hydraulic power available.

In order to show that this system is applicable to high dams, the case is worked out of a movable dam, 92 feet high, at Kalabsheh on the Nile, which was one of the sites submitted for consideration to the commission of engineers. The Author divides the fall into four equal stages, the lowest weir being in two panels, and the others in four, six and eight respectively. Each pier is 164 feet long by 9·84 feet thick. There would be fifty channels of 16·4 feet width each between the piers, closed by 200 steel sluices or shutters ranging in height from 23 feet to no less than 92 feet, all of which would have to be raised and lowered for the regulation of the reservoir. The foundations and the masonry floor of the weir would be built by caissons with compressed air. The cost is estimated at £1,200,000, whereas the masonry dam at Assouan was estimated by the other members of the Commission at £1,430,000, a figure which the Author considers too low.

A weir at Kalabsheh would retain a far greater quantity of water for the same height of weir than would a weir at Assouan. Taking the figures of cost as above given and adding to the Assouan estimate £200,000, the estimated cost of removing the temples of Philæ, the cost per unit of water impounded would be twice as great for the masonry dam at Assouan as for the "cascade" movable weir at Kalabsheh. If it were not that the foundations at Assouan can be done in the dry, while at Kalabsheh the depth of water is so great as to necessitate the use of compressed air, the difference would be still greater.[3]

C. F. F.

---

[1] *Vide* Annales des Ponts et Chaussées, 1873, Part II, p. 118.

[2] *Ibid*, 1876, Part I, p. 320; also Minutes of Proceedings Inst. C.E., vol. xliv. p. 268.

[3] Sir B. Baker, at the discussion of Mr. Boulé's project in Egypt, pointed out that a few Dervishes with a Nile-boat loaded with powder might readily blow up some of Mr. Boulé's 92-feet high sluices, when the rush of the 3,600,000,000 tons of water impounded would sweep away the whole dam and deluge the country below. As regards estimated cost, the existing Nile barrage constructed by French engineers, according to Sir B. Baker, cost fully £1,200,000, although it dams up the Nile only 12 feet instead of 92 feet.—SEC. INST. C.E.

Wet-dock at Nieuport. By Charles Piens.

(Annales des Travaux publics de Belgique, 1894, vol. li., p. 167.)

The trade of Nieuport was, until the completion of the dock described in this article, carried on at tidal wharves, connected with the sea by a channel 2½ miles in length. This channel receives the drainage of the district, and is also connected by locks with the inland navigations. It is defended at its mouth by timber jetties, and opens into the roadstead of Westdiep, considered the best on the coast.[1] Owing to the insufficiency of water at the entrance, dredging was resorted to in 1888, and in the course of five seasons an increase of depth of nearly 10 feet has been obtained by the removal of somewhat over 1,000,000 cubic yards of sand. This dredging was done by contract at prices of from 3*d.* to 6*d.* per cubic yard. It is supposed that it will be necessary to remove over 100,000 cubic yards annually in order to maintain the present situation. The depth now available is 8 feet at low water of spring tides.

The entrance being thus improved, it became necessary, in order to satisfy the needs of the trade, to improve the interior facilities, which were defective in respect to the length of the channel and its tortuous character, and also in that vessels had to take the ground at low water alongside the wharves. A wet dock has therefore been built with a straight cut from the old channel up to it.

The entrance is 49·2 feet wide, with two pairs of greenheart gates pointing in opposite directions. The depth of water on the sill is 20·3 feet at neaps, and 23·3 feet at springs. The foundation being sand of great depth, the entrance is founded directly on the sand with an invert 13·1 feet thick, made of concrete for half the thickness, and brickwork above, with a covering of masonry. At each end of the invert a curtain-wall of concrete, 10 feet thick, is carried down to a depth of 24·6 feet below the sill, with sheet piling on each side. Two rows of sheet piling are also carried across transversely between the wing walls at each end, and the bottom is floored with concrete between the wing walls.

A considerable space is devoted to the discussion of the thickness that is necessary for inverts in cases of this kind, where they may be exposed to a considerable head of water. The Author considers that the stresses on the invert are not those due to the actual maximum differences of level of the water on the two sides of the gates, but only those due to the mean difference, since the pressure is only slowly propagated through a large intermediate mass of compact sand. If a gauge were connected to the sand below the foundation of the invert it would behave in the same way as the

[1] *Vide* Demey, "Étude sur le régime de la côte de Belgique et sur les moyens d'améliorer les ports du littoral," Brussels, 1885.

mean-tide gauge of Mr. Lallemand,[1] and would indicate the mean head of water on the invert during several consecutive tides.

The invert cracked longitudinally after the walls were completed, and while they were being backed up. This crack gradually opened until it showed a maximum width of 1½ inch, tapering to nothing at the underside of the invert. Such cracks are not unusual, and arise from unequal settlement of the walls and the invert. When the movement ceased the crack was carefully filled with Portland cement, and subsequently, when the dock had been tried, no filtration of water was perceptible.

The dock is about 1,310 feet long, its greatest width being 492 feet. Provision is made for future enlargement. It has a depth of water always exceeding 21·3 feet. It is surrounded by pitched slopes, and on one side are four timber wharves, each 34 feet wide.

It was originally intended to dredge out the site of the entrance and put in a foundation of concrete deposited under water within a complete enclosure of sheet piling, since it was feared that to attempt to pump out the excavation would lead to an exaggerated expense, considering the nature of the soil. The experience of the works at Dunkirk, however, encouraged the belief that these fears were groundless, and there being also a distrust of the system of depositing concrete under water, it was eventually decided to do all the work in the dry. It was calculated from the data obtainable from other works that pumping power, to cope with a quantity of 9,000 cubic feet per hour, would be necessary for the entrance alone, and it was thought that this power should be in duplicate as a precaution. The quantity actually pumped turned out to be little more than one-third of this quantity, and included the drainage from the excavation of the dock, which would probably be 15 per cent. of the whole amount. A centrifugal pump of 9 inches diameter was used, with a 35-HP. portable engine, the reserve pump being of 6 inches, with a 28-HP. engine. The curtain walls at the two ends of the entrance were first put in between piles sunk by the water-jet. Afterwards no difficulty was found in carrying all water in grips to the central well, placed in the middle of the entrance, and in getting the concrete satisfactorily put in. The absence of springs and the small amount of water greatly contributed to the success of the work. The experience here gained shows that it is quite possible to carry out works of this kind in sand under a great head of water, if sufficient pumping power is provided to lower the water well below every part of the foundation, and if proper care is taken in choosing the site of the well or wells. The Paper is accompanied by five large plates of engravings, and also diagrams in the text.

C. F. F.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. cii. p. 349.

The Ratio between the Surface-Velocity and Mean Velocity in the Wet Section of a Mill-race. By D. Wisboom.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1893–94, p. 108.)

In conducting trials to ascertain the work performed by the new draining engines in the Herpt and Bern polder, experiments were also made as to the ratio between the surface and mean velocities in the channel carrying off the water from the engines. The actual quantity was measured by a gauge weir of 2 metres (6½ feet) width in the clear, constructed according to the description by Bazin in the Annales des Ponts et Chaussées of October, 1888. The volume being thus accurately known, this gave the mean velocity in the channel, which had been carefully measured and normalized. The surface velocity being then observed under different conditions of flow, the mean coefficient of ratio between the two velocities was obtained. From these experiments the conclusion was drawn that this coefficient was from 0·60 to 0·65, or much less than that usually taken at 0·80, or that given by Bazin as 0·71 to 0·72 for channels with earth banks.

H. S.

The Construction of a Culvert on the Monier system near Heusden. By R. P. T. Tutein Nolthenius.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1893–94, p. 39.)

The system of construction invented by Monier consists of a combination of iron rods with, and embedded in, concrete, in such a way that the concrete principally is submitted to compression while the iron resists the stresses. As good results were said to be obtained by this mode of building in other countries, it was decided to give it a trial in a culvert to be placed in a summer dike near Heusden, to drain the lands outside the main dikes, which are submerged only during high floods in the river Maas, but in summer utilized for agricultural purposes.

A contract was entered into with the patentees for Germany, to build according to their system a culvert, the foundation to be laid by others. The contractors were left free to select the form of cross-section they judged the most suitable, but giving a clear area of 7 square metres in a height of 2·80 metres. The form chosen, an elliptical arch, 3·05 metres wide and 3 metres high, fulfilled this condition. After the foundation, consisting of a concrete slab, had been laid, and the timber centre had been placed, the work of turning the arch was commenced on the 7th August, 1893.

At first, rods of 6·2 millimetres diameter were laid horizontally on the centering at distances of 50 to 70 centimetres, and over

these, rods of 9·5 millimetres, according to the form of the proposed arch, at right-angles to the first set of rods and at a distance from each other of 0·085 metre. In encircling the culvert three lengths of rod of 4 metres each were required, and these were joined simply by lashing two ends together with iron-wire over a length of from 20 to 40 centimetres. Over these rods were then laid at right-angles, rods of 6·2 millimetres diameter, at distances from each other of 0·077 metre, and fastened to the underlying rods with iron wire. As soon as this iron netting was completed, the whole was filled in and covered over by Portland cement concrete, of 1 part cement, 2 sand, 1 gravel. After six days the centering was removed, and the intrados of the arch and inside of the verticals were rendered with concrete of the same proportions, with a finishing layer of 1 cement to 1 sand.

The iron network took eleven days to finish, the concreting six days, and the rendering another six days, the whole of the operations being completed in twenty-seven days. The contents are 60 cubic metres, and the price paid was 68 florins per cubic metre. The trials as to the strength of the structure gave every satisfaction.

In experiments conducted with similar combinations it was shown that the iron network embedded increased six times the resistance of a slab of concrete. The adhesion between iron and concrete seemed to be perfect, and it could be considered a homogeneous mass. The Author investigated by mathematical analysis, which he gives in detail, the stresses and strains set up in the material, and became convinced of its trustworthy character. Many instances of successful application of it are given in the Paper, which is accompanied by several drawings and diagrams.

H. S.

The Currents in the "Krabbersgat," near Enkhuizen.

By A. Keurenaer.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1893–94, p. 116.)

In 1865 the Government decided to improve the "Krabbersgat," one of the passes between the shallows in the Zuider Zee, leading from Amsterdam to the northern provinces of the Netherlands, and which was considered a safer fairway than that through the "Hoornsche Gat" further eastward. The work principally consists of a leading dam in a direction nearly north-east to south-west, more or less parallel to the coastline, and serving at the same time as a breakwater to the port of Enkhuizen. The fairway thus inclosed is 210 wide and deep 10 Amsterdam feet below mean high water, equal to 2·30 metres below low water, except at the northern entrance, where an additional depth is found of 0·80 metre. Opposite the northern end of the leading dam, and attached to the shore, a dam, laid north-eastward and bending in a northern

direction, leads the flood-current into the channel. Only opposite the port of Enkhuizen the top level of the dam reaches to about 0·50 metre above mean high water, whereas the rest lies at mean high-water level, but at the top of high floods is often submerged.

From numerous observations taken, as to the velocity of the currents through the pass, it is shown that the ebb current is much stronger than the flood current, the first reaching a maximum velocity of 1·03 metre per second, while that of the latter did not exceed 0·75 metre per second. Outside the pass greater velocities were observed. Calculations showed that the quantities of water flowing through the pass during flood and ebb on the 25th August, 1887, were respectively, 8,626,954 cubic metres and 8,884,514 cubic metres, or 257,560 cubic metres more during ebb than during flood. On the 31st October following, these quantities were 5,768,318 and 13,867,236, or a difference in excess of ebb over flood of 8,128,918 cubic metres. After high spring tides it may be safely concluded that this excess is much greater. The ebb current, therefore, is the principal agent for maintaining the depth through the pass. The observations were made by means of the usual floats. In the discussion which followed the reading of the Paper, the use of more modern and perfected instruments for measuring current-velocities was advocated, so as to obtain more trustworthy information as to the strength of currents near the bottom, and on their influence on the maintenance of the required depths. The Paper is illustrated with numerous drawings and diagrams.

H. S.

The Defence against Erosion of the Banks of the Voorne Canal.

By F. L. Ortt.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1893–94, p. 105.)

The length of the canal through Voorne between the locks is 9,705 metres, its bottom width 10 metres, slopes 2¼ to 1, width at canal level 34 to 35 metres, and the depth under that level 6·20 metres. Before 1873 the mean canal-level was that of mean low-water at Hellevoetsluis; since, it has been raised 0·78 metre. For the execution of repairs this level can be lowered 0·80 metre, or for purposes of navigation raised 0·55 metre. The canal-banks are defended against erosion by reeds growing on the slopes, between the maximum high- and low-levels on the canal. Since 1873 the nature of the traffic through the canal has markedly changed. Before that year it was used principally by sea-going vessels; since, nearly exclusively for internal navigation. The number of sea-going ships passing through diminished from 1,183 in 1877 to 26 in 1892; while the vessels for internal navigation, numbering, in 1877, 2,941, increased to 7,282 in 1892, principally

small screw steamers. These steamers cause the principal damage to the banks, and when steaming through at the rate of 8 to 10 miles an hour set up a following wave of from 30 to 62 centimetres from crest to hollow.

The greatest damage to reeds occurs when the canal-level falls after a sharp frost, when the ice frozen round the plants pulls these down with its weight. Where these are torn out they are replaced by sods containing reed roots, measuring about 10 inches each way, thick, broad, and long. Where the damage is caused by undermining, fascine work of some kind or other is employed, but the total average expenditure for maintenance of the canal-banks from 1888 to 1892, per year and per kilometre only amounted to 28·72 florins, or about £3 16*s.* 8*d.* per mile.

H. S.

Rock-excavation under Water at Oswego, U.S.A.

By W. P. Judson, M. Inst. C.E.

(Report of the Chief of Engineers, U.S. Army, 1892–93, Appendix QQ, p. 3159.)

The object of this work was to give a depth of 15 feet at extreme low-water level in the inner harbour of Oswego on Lake Ontario. The area to be deepened was about 4,500 square yards, and the quantity of solid rock to be removed was determined by a careful survey to be 2,956 cubic yards. A contract was let for the drilling, blasting, and removal of this rock at $2¾ (nearly 11*s.* 6*d.*) per cubic yard, measured in place, no payment being due for any excavation below grade, nor for any material except the solid rock. The rock is a sandstone known as "graywacke," varying greatly in hardness.

The method adopted was that of drilling by steam-power from a barge, and blasting with dynamite cartridges, the barge being followed by a "dipper" dredger which picked up the broken rock. The drill barge was 82 feet long by 26 feet wide, drawing 2½ feet. It carried two Ingersoll drills with 5-inch steam cylinder and 7-inch stroke, each drill being attached to the piston of a hydraulic cylinder of 6 inches diameter and 12 feet stroke. By this means the drill could be quickly withdrawn from the hole, if it jammed, or when the hole was finished. The drill frames were mounted on rails, so as to be easily moved fore and aft along the barge. The drill was 26 feet in length, the lower end being of 2-inch octagon steel with a 3¼-inch diamond point. The holes were drilled from 2 to 4 feet below grade and usually 5 feet apart. The average depth of the holes was 5¼ feet, and the average time of drilling each hole, one hour. Before the drill was lowered into position, a casing-pipe of 4½-inch tube was placed on the bottom, with holes in its sides to allow the chips to escape. As soon as a hole was finished, the cartridge, weighing 2¾ lbs. (75 per cent. dynamite), was

lowered through the casing-pipe in a loading-pipe 3 feet long. A plunger was then lowered to hold the cartridge down, while the loading-pipe was withdrawn and the casing-pipe raised 4 or 5 feet from the bottom, with the electric fuse-wires passing through it. From stopping the drill to the time of explosion required in ordinary work three minutes, and to move the drill to its next position and to get it to work again ordinarily required two minutes. The barge was anchored by four spuds of oak at the four corners, worked by steam-hoists.

The rock was usually broken into lumps of 1 or 2 cubic feet, the dredger lifting a cubic yard or more at each dip. Occasionally a piece of more than a cubic yard would be brought up, which could not pass through the bucket. In these cases the bucket was lowered to rest on the hopper barge; a hole was drilled by hand, and the lump broken by a charge of 6 to 8 ounces of dynamite. No damage to the bucket or barge resulted from these explosions.

The report is accompanied by four photographs.

C. F. F.

NOTE.—The same method of excavating rock under water was recently used by the U.S. Government in deepening the St. Mary River at the outlet from Lake Superior. In this case the work is stated, in the same report, p. 2993, to have been done at prices averaging 1¼ dollar (or 6*s.* 3*d.*) per cubic yard. There was a very much greater quantity to be excavated than at Oswego, both in area and in depth, and the rock was also softer. The holes were about 12 feet into the rock, and were said to be drilled in some cases at the rate of 1 foot per minute. Two cartridges were used in each hole, weighing together 10 lbs. (90 per cent. dynamite). See also Minutes of Proceedings Inst. C.E., vol. cviii. p. 432, and vol. cxix. p. 209, as to similar work in the Danube.—C. F. F.

Asphalt-Cement Paving.

(Zeitschrift für Transportwesen und Strassenbau, 1894, p. 325.)

Attention is drawn to the fact that the use of asphalt in the liquid state for paving-purposes has been almost entirely superceded by the use of compressed asphalt; but the means of providing a permanent even pavement or carriage-way are still far from perfect. It is stated that one of the chief disadvantages experienced, particularly in the use of liquid asphalt—even when the best materials are employed—is that a combination between the concrete foundation and the asphalt does not take place, and on account of this the pavement suffers sensibly when subjected to heavy traffic, and in many cases an entrance is made for water to lodge between the asphalt and the bed of concrete. In order that a compressed asphalt-pavement shall be as perfect as possible, it is necessary that the following conditions be fulfilled, viz., the asphalt layer must be of a uniform density throughout, and able to distribute uniformly as far as possible the pressure upon it in all directions; complete internal combination must take place between the

paving and its foundation-bed, and lastly the asphalt must be such that it can be laid in varying thicknesses to suit the traffic upon it, that is to say, for a footpath a thickness of about $\frac{3}{4}$ inch, and for the carriage-way of from 1 inch to $1\frac{1}{2}$ inch. If these conditions be fulfilled the wearing away of the asphalt will be fairly uniform throughout its area, extending down to its foundation-bed, the latter being preserved from damage by the penetration of water, and considerable economy both in the making and the maintenance would follow. As a noteworthy attempt to achieve these results Mr. Löhr, of Frankfort-on-Main, has patented a process by which asphalt-powder is amalgamated with cement-concrete in suitable and varying thicknesses by mechanism under high pressure, and is thus formed into an inseparable whole; the blocks are laid in mortar on the concrete-bed of the carriage-way, whilst in the case of footpaths they are laid on a well-rolled underground. A thickness of $2\frac{1}{2}$ inches is used for carriage-ways, and $1\frac{3}{4}$ inch for footpaths. Experiments with these pavements have proved that a complete internal combination of both materials, otherwise so heterogeneous in character, is obtained. Trial lengths have been laid in Frankfort during the past year, some of which are laid between much-used tramway-lines, and have hitherto given great satisfaction; and in the opinion of the Author it may be assumed that Mr. Löhr's paving will enter with success into the competition which has been carried on since the introduction of noiseless pavements. The chief advantages resulting in the use of this pavement are that it is comparatively noiseless, it is quickly and easily laid, and that repairs brought about by excavation to pipes or sewers are equally easily made.

J. A. T.

Flow of Rain-Water in Drainage-Sewers. By A. FRÜHLING.

(Der Civilingenieur, 1894, p. 623.)

Of a quantity of rain R which falls on the ground only a part ψ R reaches the drainage sewer (ψ being called by Baumeister the coefficient of density), the rest either wets the surface and is evaporated, or sinks into the soil. The values of ψ vary with the nature of the ground area or roof area; for metal, glass, slate and tile roofs $\psi = 0 \cdot 95$; for gardens &c. ψ = between $0 \cdot 00$ and $0 \cdot 25$. The values of ψ to be taken for different parts of a town are discussed.

Let Q be the greatest flow in the sewer per second, F the drainage area, q the greatest rainfall per unit of area per second, and ϕ a coefficient of lag. Then $Q = \phi \, \psi \, qF$.

Q will be less than $\psi \, qF$ if the time which the rain-water requires to flow through the whole length of the sewer is greater than the time during which the rain falls. That is, the influence of lag on the cross section of a sewer is only felt when the length

of the sewer is greater than the product of the velocity in the sewer and the time of the rainfall. Taking as basis observations of rain duration made in Breslau, and a minimum velocity of ½ metre per second, the Author concludes that 1,360 metres is the shortest length of sewer on which a diminution of section due to lag is allowable; and that therefore, for sewers of small towns, lag may be left out of consideration.

A. S.

Mechanism of the Spring of Vaucluse. By LÉON DYRION.

(Bulletin de la Direction de l'Hydraulique Agricole, 1894, p. 69.)

In the Département de Vaucluse, the two rivers Nesque and Coulon only discharge 12·5 per cent. of the rainfall on their drainage areas, while the River Durance, whose tributaries flow off similar ground, discharges 70 per cent. of the rainfall. On the other hand, the flow from the Spring of Vaucluse, between the two, makes up the difference between the 70 per cent. of the rainfall from the combined watersheds of the Nesque and Coulon, and the quantity flowing away down their channels. This tends to prove that the drainage area of these two rivers feeds this spring.

Explorations have shown that the mechanism of the spring consists of fissures converging into a series of caverns, filled, or partially filled, with water, forming large reservoirs, which communicate with each other by means of fissures, of the nature of siphon-pipes; consequently the emptying of the upper or an intermediate reservoir has comparative little effect on the rate of discharge of the spring. At the lower end of the chain of caverns is a natural dam through which the springs emerge when not overflowing it. This conformation has the effect of delaying the discharge from the spring of the rain-water falling upon the watershed, thus rendering the discharge of the spring throughout the year more uniform than the rainfall.

The Author proposes a scheme for constructing a tunnel 550 yards long and 24 square yards in section through the hill, forming the natural dam, and providing it with three sluices worked from shafts, so that flood-waters can be run off more expeditiously and the continuous action of injurious pressures on the system prevented; also to ensure a continuous delivery into the river throughout the summer of 650 cubic feet per second.

A. W. B.

The Improvement of the Water-Supply of Marseilles.

By C. Rebuffel.

(Bulletin de la Société Scientifique Industrielle de Marseille, 1894, p. 179.)

The present water-supply of Marseilles is taken from the River Durance by means of the canal of that name, but both its conveyance and distribution are defective. The canal has to convey more water than it was designed for, and there is considerable leakage and consequent damage, necessitating the canal being turned off for repairs for a fortnight twice yearly. The open canal passes a distance of 3¾ miles through the precincts of the town, rendering the water liable to contamination; and in its course it is utilized for power purposes and returned to the channel. The distribution-pipes ramify from the termination of this channel, so that the water becomes stagnant in the dead-ends of the pipes; the sizes of the pipes are not properly proportioned to the quantity of water they are required to discharge, consequently, in some districts, at the period of maximum draught in the main, the pressure is insufficient to force the water into the house-cisterns, into which it passes through orifices supposed to be proportioned according to the supply paid for, but in many cases they have been enlarged above that size to counteract the defective pressure; consequently, there is practically no check on the quantity passing into these cisterns, which increases as the draught in the pipes diminishes and runs to waste down the overflow.

The supply, already inadequate, will be quite insufficient when the system of water-carriage of the sewage, now being carried out, comes into action.

The Author propounds a new scheme of distribution, utilizing, at all events provisionally, the water of the River Durance. This involves the repair of the intake-works from the river and increasing the stability of its banks at that place; the repair of the canal, 57 miles long, in a permanent manner so as to obviate the biennial stoppages for repairs; the overhauling, cleaning and enlarging of the settling- and storage-reservoirs on the line of the canal, so that when it is necessary to turn off the water for the repairs the supply may not be stopped; the purification of the water by filtration through polarite or by Anderson's revolving purifiers.

The Author in his scheme of distribution allows for having ultimately to supply an area of 5,000 acres in and around Marseilles, with a population of 550,000 inhabitants, allowing 26 gallons per head per day; this amounts to 14,300,000 gallons per day.

The Author proposes to avoid the present waste by introducing ball-cocks on the cisterns, and to prevent the stagnation by connecting the distributing-pipes in circuits. He divides the area of

supply into two zones of high- and low-pressures supplying approximately equal numbers of consumers.

The formation of the ground permits of a service-reservoir at the upper and lower extremities of each zone of distribution. The latter fill at night and so maintain the pressure in the distributing-pipes, during the period of maximum draught, with smaller pipes than would be possible without them. In the upper zone the higher reservoir has four compartments, of which two would be built to start with, each capable of holding 1,370,000 gallons, whilst the compartments of the similar lower reservoir, 65 feet below the former, each contain 1,100,000 gallons. The two are connected together by a pipe 6·3 miles long, with a diameter varying from 2·6 feet to 1·6 foot, in order to utilize portions of the old mains which are in a satisfactory state.

The lower zone has two similar reservoirs situated 164 feet below the former, connected by a pipe 5·3 miles long and 2·3 feet diameter. The service-pipes are not connected to the mains but to distributing-pipes of smaller diameter.

The cost of the above works is estimated at £480,000. Three possible alternate methods of supply are mentioned. From the shaft of La Madrague, formed in the search for coal, near to the town. From the springs of Saint-Pons, fed from the fissures of the limestone hills of Sainte-Baume, 22 miles distant. Although the yield of these springs is at present insufficient, the Author suggests that it might be increased by means of shafts. From the Fontaine-l'Evêque, springs situated in the Département du Var, fed by water from the fissures in the limestone rock of the Plan-de-Canjuers, 77 miles distant. It is one of the principal feeders of the River Verdon, and a storage reservoir to compensate for the summer abstraction would be necessary. A natural lake exists which, with a little alteration, could be utilized for this purpose.

A. W. B.

Dunning's Dam, near Scranton, Pa., U.S.

By E. Sherman Gould, M. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, November, 1894, p. 389.)

The reservoir formed by this dam replaces the original small one for the supply of Scranton, Pa., which has a daily water-consumption of 6 or 7 million gallons. The reservoir is formed in the valley of the Roaring Brook, and has a drainage area of 36 square miles and a capacity of 1,000 million gallons.

At the most advantageous site for the dam two railways approach the Roaring Brook—on the south side the Delaware, Lackawanna and Western Railway, and at the north side the Erie and Wyoming Railway. As the overflow-level of the reservoir is 7 feet above the former and 1 foot below the latter, return walls had to be carried

alongside the railways in the first case 1,200 feet long, and the other 600 feet.

The dam consists on the north side of an earthenwork dam with a masonry core, 12 feet wide at the bottom and narrowing to 3 feet at the top. This joins on to and is about the same length as the overflow, which consists of a masonry dam on the outside, but with the earthwork slope continued on the inside. Its length is 153 feet, and its crest is 5 feet below the top of the wall along the railway on the south side, and 8·5 feet below the adjoining earthen dam, and about 50 feet above the original ground-level, the thickness being 40 feet at that point. The masonry of the outer slope is stepped so as to break the force of the overflowing water. An apron of concrete covered over with dry stone-pitching is formed at the foot of the slope. The foundation of the dam is clay as far as the middle of the overflow length, when it changes abruptly to rock. At the end of the overflow length on the north side on the outer slope is a retaining-wall to catch the slope of the earthen bank, and on the south side the draw-off culvert, containing two pipes 48 inches and 36 inches diameter respectively, each with two stop-cocks on it. There is also an arrangement in the tower at the water-face for filling in stop-planks in case the valves should require repairs.

The wing-wall alongside the railway on the south side, which is about 40 feet high above its foundations, and 25 feet above the inside slope, with an average thickness of 10 feet, has developed a crack about one-third of its length from the dam, due most probably to contraction, as the work was done in the summer.

A. W. B.

Industrial Application of Ozone. By O. Froelich.

(L'Eclairage Électrique, 1895, p. 509.)

The Author describes, from a Paper read by him before the Electro-Chemical Society at Berlin, the apparatus most suitable for the production of ozone as being a development of the old Siemens ozone tubes. These he considers both more economical when at work and also less costly to erect than any recent apparatus devised for the same end. Instead of two concentric tubes of tin-foil covered with mica on adjacent surfaces, the Author uses water in the place of tin-foil and retains the annular air-passage by means of glass tubes. The great advantage of this construction is that with the glass the blue light appearing when ozone is being formed can be seen, and the electric regulation effected accordingly.

The Author finds that alternating currents produced by commercial alternators do not give the best results. He has constructed a very simple alternator which has some peculiarly

shaped electromotive-force curves, particularly adapted for the production of ozone, but the design of machine is not disclosed.

The only adjustment necessary to ensure the best efficiency in the ozone manufacture is that of the electromotive forces of the alternator. The heating of the dielectric when the apparatus is at work is in proportion to the production of ozone. In the old forms of apparatus it was necessary to cool the tubes by circulating water round them. The Author finds that a horse-power hour produces scarcely 308 grains of ozone, of which only one-third is available chemically, whereas the same energy would give electrolytically 1,080 grains of oxygen. It follows from this that ozone should only be used commercially when some special reason exists and when simple reagents cannot replace it.

In some cases it is found advantageous to use ozone in connecting with other chemicals such as terebenthine or ammonium chloride, in which conjunction it has a rapid and powerfully bleaching action.

The Author summarises and describes the following uses to which ozone may be used practically.

Sterilization.—Dr. Ohlmüller has proved that ozone destroys readily the bacilla of cholera, typhus fever, &c., and could have been used with advantage in hospitals. It can be used to purify the air in crowded rooms, but the pungent odour makes this course disagreeable.

Phylloxera.—This vineyard pest is killed by a solution of ozone, but the mechanical difficulty of getting the liquid to reach all the roots attacked has not up to the present been satisfactorily overcome.

Wines.—Light sourish wines are not much changed by ozone, but sweet wines are converted in liqueurs.

Seasoning of Wood.—The action of ozone is to mature and harden wood, and for this purpose has been used in a piano factory at Stettin since 1881.

Bleaching Linen.—The Author has set up an ozone-making plant at the bleaching works at Greiffenberg in Silesia, and for several years has tried to bleach linen commercially by ozone. So far, the process has not been commercially successful, but in cases the last processes of bleaching in the fields can be economically dispensed with in favour of the ozone chamber.

The Author gives blocks of the plant used and the ozone chamber.

The other industrial applications of ozone described are bleaching of wax, starch derivatives, and thickening linseed oil for the linoleum trade.

R. W. W.

On the Disinfection of Fecal Matters by Peat, and the General Treatment of Excreta. By Prof. A. GÄRTNER.

(Zeitschrift für Hygiene, 1894, p. 263.)

Reference is made to the action of the German Agricultural Society, which by its invitations to various Hygienic and Chemical Institutes to undertake an investigation into the value of peat as a disinfecting agent,[1] called attention to this matter. The essays of Klipstein, of Stutzer and Bury, and of Fränkel, who all of them studied this subject independently of one another, are recalled, and it is pointed out that great differences exist in the methods upon which they worked. The questions propounded by the Agricultural Society were directed firstly to the possibility of destroying the germs of infectious diseases contained in the excreta, more especially those of cholera, by the application of powdered peat; and secondly to the advantage or otherwise of the addition to the peat of substances which would either be harmless to it if used as a manure, or which might even increase its value in this respect. Two descriptions of peat were employed, as also kainit, a sulphate of magnesia and potash, with a neutral re-action to test-paper, and super-phosphate of lime which was strongly acid, containing as it did the bulk of the phosphoric acid in an uncombined state. As the result of the numerous experiments, full details of which are given, the Author states that the use of peat, even if mixed with concentrated acids, does not ensure absolutely safe disinfection, unless steps are taken to bring about an intimate admixture between these substances and the fecal matters. Sulphuric and phosphoric acids share with all other disinfecting agents the property of not readily penetrating into the excreta when these substances are in the pasty condition in which they exist in tubs or midden-pits. Milk of lime answers far better than peat does for the disinfection of the dejections of typhoid-fever and cholera patients, in cases in which certainty of action is of importance. It would appear that, in order to effect safe disinfection with peat-dust, recourse must be made to mechanical stirring of the same with the excreta. When employing peat mixed with acid as a disinfecting agent, and in order to avoid the loss of the ammonia, sulphuric acid should be present to the extent of not less than 0·2 per cent. of the whole mass of mixed dejections.

On the subject of dry systems of dealing with excreta, the Author insists upon the importance of the removal at regulated intervals of the contents of the tubs or middens. When tubs are made use of they are generally changed so often that the pathogenic germs will be removed while their vitality remains unimpaired, but in middens the contents are stored up long enough for the destruction of the greater part of the disease-germs. When

[1] Minutes of Proceedings Inst. C.E., vol. cxiv. p. 430, and vol. cxv. p. 446.

the tubs are not properly disinfected after each emptying there is a danger, owing to the exchange of tubs, of conveying infectious matters from house to house; but it is shown that with proper precautions this danger is chiefly imaginary. When the midden-pits are entirely covered up, considerable volumes of gas generated by the putrefying contents are often discharged into dwellings, and give rise to disagreeable smells which can be perceived all over the house. Erismann calculates that each cubic metre of excreta may evolve 18 cubic metres of gas in twenty-four hours, the substitution of a pail- or tub-system for middens is consequently recommended. Various plans of ventilation of middens are discussed, and the Author points out the advantages to be derived by employing the heated column of air in the kitchen chimney for the extraction of the foul gases from the midden-pit and the soil-pipe. However perfect in other respects may be the plan adopted, it is advisable to employ disinfectants in the closets, and powdered peat, treated with sulphuric acid, is well adapted for this purpose.

G. R. R.

On the Evaporation of Quicksilver in Dwellings.

By Prof. K. A. H. Mörner, of Stockholm.

(Zeitschrift für Hygiene, 1894, p. 251.)

When corrosive-sublimate first began to be employed for the disinfection of dwellings, fears were expressed by some that the sublimate might become volatilized and thus give rise to cases of mercurial poisoning. But nothing of the kind was found to occur when the rooms, after having been disinfected by this means, were again occupied. The experiments undertaken by Sjöqvist demonstrated that there were no grounds for the apprehension that corrosive-sublimate, in an undecomposed state, would give off dangerous fumes at any temperature likely to occur in dwelling-rooms. Moreover, the investigation of the urine of persons inhabiting such rooms, after disinfection had taken place, gave only the faintest traces of mercury, and this only for a short time (a few months at most) after the operation. A question arising out of this, which has hitherto been neglected, is whether it may be possible for the sublimate to be gradually reduced to metallic quicksilver, which latter is known to become volatilized at ordinary temperatures and to give rise to exhalations of a very poisonous nature. The sublimate in a dry state is, it is true, a very stable compound, but, on the other hand, a solution of this salt is decomposed even by the action of light, leading to the formation of the sub-chloride, which is certainly more readily decomposed than the chloride. This reduction process would be facilitated by the presence of organic matters, as, for instance, in carpets, and such a reaction would still more readily be effected by the lime in

the plaster, or by the soda solution which has been advocated as a wash for the walls after the disinfection is over. The Author deemed it expedient to investigate these matters experimentally. For this purpose he took samples of carpet from a room which had been disinfected with a solution of one part of sublimate in 3,000 parts of water, and cut the carpet into shreds which were placed in a glass vessel with gold leaf under precautions which he describes. It was found after four weeks that notable quantities of metallic quicksilver had become attached to the gold leaves, and globules of the mercury could plainly be seen under the microscope. Four series of experiments of varying duration were carried out, and it was evident in each case that the carpet had given off vapours of metallic quicksilver.

Throughout this period, the room from which the specimens of carpet had been taken was occupied by a family of adults and children, and though their urine was systematically tested for mercury, only occasional traces were found. Further investigations, described by the Author, were undertaken on account of cases of illness which were attributed to mercurial poisoning, and which occurred elsewhere long after the disinfection with the sublimate had taken place. The symptons are set forth in detail, and in certain instances very large quantities of mercury were found in the urine. The carpet was, on this occasion, ascertained to be the source of the mercurial fumes. As the Author was able to demonstrate the presence of considerable quantities of mercury in the air of rooms which had been disinfected with corrosive-sublimate, he advocates the sparing use of this substance for the purpose in question.

G. R. R.

Heating of Rooms by Gas-Stoves and by Anthracite-Stoves.

By Aimé Girard.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1894, p. 625.)

To study the relative advantages and economy of heating rooms by gas-stoves and by anthracite-stoves, the Author during two winters, 1891–2 and 1892–3, kept an anthracite-stove in one of his apartments, and a gas-stove in another. In the former the fire was kept constantly burning, in the latter the gas was burned only during the actual time the room was occupied. The room heated by gas had a capacity of 3,500 cubic feet, the room heated by anthracite 2,600 cubic feet; the smaller capacity of the latter room being to the advantage of the anthracite-stove. The gas-stove was lit every evening at 8 P.M. and kept burning till 8 A.M. next morning, the gas-cock being more or less open according as the external temperature was lower or higher. The other stove was charged each day with a bucketful of anthracite. Both rooms were kept at a temperature of from 15° to 17° C. It should be

mentioned that in periods of comparatively high temperature during these two winters it was necessary to keep the anthracite-stove always going, so as to be able to produce the required heat immediately on the return of cold weather; on the other hand, it was possible to dispense entirely with the use of the gas-stove during the same periods. In 1891–2 the experiment lasted 136 days; the cost of anthracite being 4·51*d*. per day, the cost of gas 4·22*d*. per day. In 1892–3 the experiment lasted ninety-one days; the cost of anthracite and gas per day being 4·70 and 3·94*d*. respectively. In both years the price of anthracite was 49*s*. per ton, that of gas 6*s*. 9*d*. per 1,000 cubic feet.

The Author considers, that besides showing an advantage in cost of fuel, the gas-stove is to be preferred from the point of view of hygiene and security against fire.

Details of the measurements made are given in the Paper.

A. S.

A Proposal for the most advantageous Reclamation of Land in the Zuiderzee. By A. Huet.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1893–94, p. 158.)

With regard to Mr. Huet's proposed alteration of the Amsterdam ship-canal into an open channel in free communication with the North sea, the Author submits that the long-considered intention of reclaiming land from the Zuiderzee must eventually be undertaken in conjunction with the first-mentioned project. On the plans accompanying the Paper the new reclamation or polders are shown in three series, to be laid dry at consecutive periods, beginning with the sea-bottom near the present shores, whereon a depth is found not exceeding 2·50 metres below low water. The second series contain areas with depths from 2·50 metres to 3·50 metres, and the last with depths up to 4·50 metres. The whole surface so obtained for agricultural land would then be 185·990 hectares, leaving the rest of the bay in its present condition. This will act as a flushing basin for the open waterway past Amsterdam, when the great dam between Enkhuizen and Stavoren is completed. Eventually this basin or pool will lose its degree of saltness and become a fresh water lake to all intents and purposes. The estimate for the empoldering amounts to 1,000 florins per hectare, or about £34 per acre, including steam-draining engines.

H. S.

The Railway through Rotterdam. By N. T. Michaëlis.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1893–94, p. 1.)

The railway through Rotterdam, from its junction with the Holland Railway to the bridge over Mallegat on Fyenoord, is about 5 kilometres long, and consists for the greatest part of a viaduct at a level giving sufficient headway for roads, streets, canals, and the River Maas crossing its direction. In the entire work are also included fixed bridges over the Schie Canal, over the Hofplein and Stadsvest of three openings of 29·50 metres span in the clear, over the Stijgers-Gracht of 38 metres span, over the River Maas consisting of 5 spans, of which the two end openings are 64·50 metres and the three centre openings of 90 metres wide, and over the Mallegat of 20 metres span. Besides, there are two street-bridges in the embankment on Fyenoord of 15·50 metres width, and a swing-bridge over the Doode Haven giving clear passages of 18 metres for ships. Also a bridge over the Koningshaven with a middle swing span of two 19-metre openings and two fixed spans of 76 metres in the clear. The buildings include a joint station at the junction with the Holland Railway, a station in the viaduct near the exchange and a new post-office. The whole of the works is founded on piles according to the system practised in Holland, except that two of the central piers over the Maas bridge, which were built pneumatically, and the bridge over the Koningshaven, founded on a bed of hard sand. The ground in the locality is very soft and untrustworthy, and many of the piles driven in were 18 metres or 60 feet long. Part of the viaduct was located in the bed of an existing town canal, which was therefore filled in to street-level. This was also the case with the post-office, the building of which was complicated by having a tunnel in the axis of the old canal, running through its foundations and basement story. No mishaps of any importance occurred. The cofferdam for the swing pier on the Doodehaven burst several times and retarded the work, and one of the abutments of a road opening on Fyenoord burst during the night with a loud report, a vertical crack forming nearly in the centre, owing to the unequal loading of the pile-raft before the bank had been filled in between the wing-walls.

The works were started in January, 1870, and opened for public service on the 1st May, 1877. In the construction of the superstructure over 7,100 tons of wrought-, 1,800 tons of cast-, 112 tons of corrugated-iron, 1,800 tons of steel were used. The total expenditure amounted to 8,598,269 Dutch florins, or about £716,500.

The Paper gives very detailed descriptions of all the works executed, and contains a great many drawings.

H. S.

Subsidence of part of the Embankment on the Railway between Bunde and Beek-Limburg.

By A. A. C. H. van Liebergen.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1893–94, p. 133.)

The railway from Moortrecht to Venlo, constructed in 1864, runs between Bunde and Beek Elsloo over the hillside forming the eastern slope of the Maas valley. The ground, falling towards the west, consists on the surface of a loam called "Löss," overlaying a gravel bed, resting on sand, below which a dark blue clay is found. On the 25th of September, 1892, between kilometre-posts 10·240 and 10·800, where the formation level is embanked to a height of 7 metres, a subsidence took place over a distance of 75 metres. The body of the dam is tipped up from the neighbouring cutting, and consists principally of so-called greensand, a mixture of fine sand and organic matter, while the slopes are covered with clay. In 1864, during construction, some subsidence had been observed which was owing to a vertical compression of the natural soil. The accident of 1892 was caused, however, by the body of the dam sliding out sideways.

On investigation it was found that the water draining down the slope of the hill above it had impregnated the lower parts of the embankment, which was kept in a state of dampness by the impermeable nature of the covering of clay on the slopes, reducing the greensand to a consistence of porridge. The determining causes were heavy rains during the execution of some works to improve the condition of a parallel road running along the foot of the embankment; the drainage of the higher ground being temporarily interrupted. It was also found that the old natural soil was undisturbed, as was proved when the subsided part of the bank was removed. In reconstructing the embankment a large ditch was laid on the upper side and the toe defended by a rubble wall, while at several places, trenches filled with gravel were laid across to give a better drainage to the body of the dam. In the discussion which followed the reading of this Paper, it was averred that other parts of this railway might be subject to similar accident; but it was stated that careful investigation had proved that no other spots were subject to a similar conjunction of adverse circumstances, consisting of the height of the embankment, the less desirable material of which it had been formed, and the responsibility for the drainage of the surrounding area being divided between three public authorities; that of the public works department, the State railways, and the parish, which had been the cause of procrastination. It was unanimously decided that at present the line is perfectly safe, with regard to similar dangers.

H. S.

Note on Landslips on the Railway from Paris to Lyons.

By — CARTAULT.

(Annales des Ponts et Chaussées, October, 1894, p. 377.)

The portion of this railway betwen Paris and Montereau was opened for traffic in 1849, and it might naturally be supposed that the slopes of cuttings would, by this time, have become consolidated. That is not the case however. Almost every year slips occur, and at certain points equilibrium appears to be no more nearly attained than when the cuttings were first made. Some of these slips have interrupted the traffic and have necessitated very costly works. The Author has been in charge of this part of the line for eight years, during which works of consolidation have been steadily and systematically carried out. The methods successfully applied are due largely to the patient researches of Mr. Cochin.

The soil in which these cuttings are made has a tolerably uniform constitution. Below the vegetable mould is found a succession of layers alternately permeable and impermeable, the former being of gravel or sand and the latter of clay, the whole resting on compact chalk. The surface water penetrates to the first stratum of clay, along which it flows, and the beds below are invariably found to be free from water. When a cutting is made in such a soil the regime is altered. The water flowing on the uppermost clay bed runs down the slope and is drained off in the cutting. In running down the slope it crosses the exposed edges of the lower permeable beds and penetrates slowly into them. On that side of the cutting on which the strata slope upwards from the railway the water so penetrating does not travel far and can do little harm. On the other side, however, the rain falling on the slope soaks into the lower permeable strata, and after many years, during which no indication of instability is seen, suddenly a settlement will occur. A crack opens in the surface of the ground some distance from the cutting; through this crack more water enters to complete the saturation of the mass; the vibration from trains increases the dislocation, and after a further period a wedge of earth will slide upwards on one of the clay beds, which has become thoroughly wet and polished, and fall into the cutting. The greatest inclination on which such a slide has been noted is 1 in 10. In some cases it has taken over forty years to produce the effect above described. This theory was at first received with suspicion, but it has been amply verified by observations, and works undertaken, as measures of prevention, at dangerous spots have proved thoroughly successful when based upon it. Works which were carried out at great expense before this theory gave a clue to the cause of the evil, proved only partially, or, in some cases not at all, successful. In one case where the plane of sliding cut the ditch, retaining walls had not

been effective in stopping the movement of the bank, but when the ditch was cut deeper so as to lie wholly in clay, no further movement occurred. In this case the slope of the strata was in the opposite direction to that of the surface; while one ditch received a large and constant supply of water, it was on the other side of the cutting, where no appearance of humidity was to be seen on the slope, that the slips occurred. In an adjoining portion where the plane of sliding was higher than the top of a dwarf retaining wall at the foot of the slope, dry stone filling was put in above the wall, and served to drain the exposed face of the permeable stratum and to stop the movement. In another case an embankment had been provided, on the side towards which the surface water flowed, with a deep dry stone drain, according to ordinary practice. This was done when the line was first built. The result of this proceeding was to conduct the water through an impermeable clay band into permeable strata below. Further, the dry stone drain became choked with deposits of lime and the lower clay bed carried a sheet of water over 3 feet deep, rendering the embankment most unstable. It was found necessary to drive a heading through rock, lower than the stone drain, in order to dry the ground effectually. This heading is 300 yards long, 2·3 feet wide and 5 feet high, to the crown of the arch. It is accessible for inspection. In another cutting slips commenced in 1878, and were on such a scale that one line was blocked for nearly two months, and the other for seven months, while trains were only allowed at low speed on one line for a month and on the other for nearly a year. Retaining walls with an invert and dry stone drains arrested the movements until 1890, when they recommenced. The cause of the movements was thoroughly investigated by means of trial pits. Two planes of sliding were found to exist and a heading 400 yards long was found necessary to drain the saturated mass. In other cases the foundations of culverts and bridges had been the means of enabling water to penetrate to permeable strata and render them unstable. At one embankment the settlement, since the construction of the line, amounted to 10 feet. The level having been constantly restored by fresh ballast, the middle of the embankment was occupied by a large basin filled with ballast and saturated with water. A break was imminent when, in 1887, it was decided to drive a transverse heading under the bank at the level of the rock. While this was being done, the line was settling at the rate of 2·4 inches per day and moving sideways 1·6 inch per day. The fence had moved 13 feet altogether. The heading was got through with great difficulty. Dry stone drains were also put in at the same level, by means of tunnelling, reaching from the middle of the bank to the lower edge of it, at right angles to the line. These works proved quite effectual.

The Paper concludes with some general remarks on the nature of the works to be undertaken in such cases, in which the principal point to be noted is the necessity of providing for the

drainage of the surface of the permanent way as well as that of the sub-soil.

The Paper is accompanied by numerous drawings of the works described.

C. F. F.

Strengthened Permanent Way used by the Italian Mediterranean Railway. By R. Bonnin.

(Revue générale des Chemins de fer, September, 1894, p. 126.)

The lines of the Italian Mediterranean Company between Turin and Genoa traverse the Ligurian Alps and have the steepest gradients and the longest tunnels—with the exception of the Mont Cenis, Gothard, and Arlberg tunnels—existing on European lines. Gradients of 1 in 29 are found on the Giovi line; and on the line from Sampierdarena to Ronco, constructed with a maximum gradient of 1 in 62, there is a tunnel (called the Ronco tunnel) with a length of 9,061 yards. On the latter line, which was opened in June 1889, a decided wear of the rails and their attachments was found in 1893 after four years of service. The superstructure consisted of flat-bottomed rails weighing 72½ lbs. per yard, and 29½ feet long, resting on eleven sleepers, with intermediate bed-plates, and fixed by means of prismatic spikes. The angular fish-plates are fastened together by means of five bolts. The same type of permanent way is used in the Fréjus tunnel and on the line from Vintimiglia to Genoa, where, after twelve years service considerable wear was found both of the head and bottom of the rails. Lastly, on the Busalla Pontedecimo line double-headed rails are laid in the Giovi tunnel, and it was found that after six years service the lower head had worn away to an extent of 0·47 of an inch in the chairs, at the same time the chairs penetrated from 0·47 to 0·59 of an inch into the sleepers, and the underside of the heads of the spikes were completely corroded.

With a view to obtain a permanent way of a more durable character for use in tunnels and on heavy gradients, and with a considerable traffic passing over it, special study was given to the question with the result that the following type of permanent way is being brought into service.

The rails are 39·37 feet long, with a depth of 5·9 inches, and rest on fifteen sleepers, each 8·53 feet long and having a section of 9·44 by 5·51 inches, by means of chairs weighing 42 lbs. each. The weight of the rails is 90·72 lbs. per yard.

The top table of the rail is 2·83 inches wide, and is as flat as it can be rolled, and is similar in this respect to the rails used by the French Eastern and Paris-Lyons-Mediterranean Companies. The lower table is 3·54 inches wide, in order to have as large a surface of support on the chair as possible, and is perfectly flat. The web has a thickness of 0·59 of an inch, and the fishing surfaces have an inclination of 1 to 3.

The fish-plates are 17½ inches long and weigh 35¼ lbs. each; they are fastened together by means of four bolts, 1 inch diameter, with "Grover" washers; the weight of each bolt is 2·35 lbs.

The dimensions of the chairs are 14·56 by 5·91 inches, and have a bearing area on the sleeper of 86 square inches; the weight of the chair is, as stated above, 42 lbs. It is fixed to the sleeper by means of screws, 0·86 inch diameter, with a triangular thread with a pitch of 0·39 inch. The weight of each screw is 1 lb. 3 ozs. The holes in the chairs are conical, having a diameter of 1¼ inches at the base, into which a wooden ring is fitted with a metal washer (Collet's system), similar to the one in use on the French State Railways. The wooden keys are 10 inches long, 3·15 inches deep, and 3·34 inches wide, and taper towards the end. Four screws are used in the chairs on each side of the rail-joint, but in the intermediate chairs only two screws are used.

Tables giving the weight, moment of inertia, depth and width of the rails, and the weight and dimensions of the chairs, used by various English and Continental Railway Companies, are annexed, and a Plate also, giving full details of the new Permanent Way described.

J. A. T.

Experiments on the Lubrication of Bearings made on the Paris-Lyons-Mediterranean Railway. By E. Chabal.

(Revue Générale des Chemins de Fer, Oct. 1894, p. 175.)

From 1871, the period at which the Paris-Lyons-Mediterranean Railway Company abandoned grease for lubrication for the axles of carriages and wagons and adopted oil, they, up to 1885, had made use of bronze bearings and of colza oil (pure in summer, with an addition of 10 per cent. of shale oil in winter).

In 1885 the trials made by other companies in the use of white metal bearings and mineral oils induced them to make similar experiments, and also to find out whether the substitution of wool for cotton for the lubricating wicks would not be advantageous. They consequently made a series of tests to compare the results of using (1) White metal bearings lubricated with mineral oil, (2) Bronze bearings with mineral oil, and (3) Bronze bearings with colza oil.

The Author gives the results of the tests made, which were composed of the following :—

A. Tests made from 1886 to 1889, to measure directly the resistance of wagons to traction, by means of allowing them to gravitate down a gradient and measuring the time taken. These tests have enabled the following to be compared :—

1st. The resistances of wagons having different kinds of bearings with different lubricating-oils.

2nd. The resistances of two wagons coupled together and one running alone.

3rd. The resistances of open and covered wagons.

4th. The resistances of wagons on two axles and on three axles.

B. Tests made from 1889 to 1890, to measure directly the resistances of wagons to traction, in drawing coal-trains divided into two parts of 300 tons each; this division is made only for the purpose of comparing the influences on the two parts, and measureing the resistance of each by means of two dynamometer cars,[1] and thus also enabling the resistances of wagons placed at the head of a train to be compared with those at the rear.

C. Abstracts made from 1887 to 1889 on a certain number of carriages running in service with bearings made of pure metal, and bronze, giving the mileage run over.

D. Abstracts made in 1891 of the consumption of oil on passenger-trains mounted on bearings of pure metal and lubricated (1) with colza oil, (2) with mineral oil.

E. Tests made in 1891 to determine the capillarity of the staple for lubricating wicks, whether they be of wool or cotton, and according to what oil is employed.

F. Tests made from 1888 to 1891 on carriages in service, to compare the lubricating wicks of cotton and wool.

G. Tests made in 1890 on vehicles running by themselves with two and three axles.

The Author describes in great detail the numerous experiments made, and gives diagrams and tabulated results.

The following is a summary of the conclusions arrived at.

Lubricating-wicks.—The tests made to compare the woollen wicks with those of cotton in regard to the facility with which they supply the oil have shown a superiority of delivery of from 50 per cent. to 100 per cent. in favour of the woollen wicks. It was also found that the renewals of the woollen wicks were only sixty-eight in number compared to 100 of the cotton ones, and that the woollen wicks were less liable to firing; notwithstanding the higher price of the woollen wicks, it was found economical to use them, and since May, 1893, the Paris-Lyons-Mediterranean Company have adopted them entirely.

Bearings.—The result of the tests made showed that the wear of white-metal bearings was 50 per cent. less than in the case of bronze bearings. The tests also showed that, by the use of white-metal bearings, a diminution of 20 per cent. on the resistance of fully-loaded coal-wagons, forming trains weighing 300 tons travelling at speeds of 16 miles to 26 miles an hour, was given; that, as the speed increased, this gain was diminished, but remained always 5 per cent. less. As a consequence of these tests, the Paris-Lyons-Mediterranean Company in 1893 abandoned the use of bronze bearings for carriages and wagons, and adopted white-metal bearings.

[1] Minutes of Proceedings Inst. C.E., vol. cxvii. p. 453.

Lubricants.—The tests made by abandoning carriages to themselves on a gradient have fully justified the rejection by nearly all the railway companies of grease and the adoption of oil. Grease gave, for carriages isolated and mounted on bronze bearings, an increase of resistance per ton of

25 per cent.	in comparison to	mineral oil	at low speeds	
40 „	„	colza oil	(19 miles an hour).	
3 „	„	mineral oil	at high speeds	
14 „	„	colza oil	(38 miles an hour).	

The increase of resistance would be greater in ordinary trains than indicated above for isolated carriages. From these same tests, combined with those made by means of the dynamometer cars, it was found, in comparing colza oil, mineral oil, and mixtures of these two, that colza oil is more advantageous than mineral oil, and that the mixtures are classed between the two. Taking white-metal bearings, colza oil with an addition of 10 per cent. of shale oil, appeared to be very nearly equal to pure colza oil in relation to non-resistance to traction; pure mineral oil gave in relation to pure colza oil an increase of resistance per ton of 15 per cent. for trains of 300 tons composed of fully loaded coal-wagons and running at speeds of 16 miles to 26 miles an hour. The mixtures of mineral and colza oil gave more resistance than pure colza oil, and the increase of resistances were in the same trains

13 per cent. for the mixture of 75 per cent. of mineral oil and 25 per cent. of colza oil.
7 per cent. for the mixture of 50 per cent. of mineral oil and 50 per cent. of colza oil.
3 per cent. for the mixture of 25 per cent. of mineral oil and 75 per cent. of colza oil.

It was also found that in summer the consumption of colza oil was only 0·8 of that of mineral oil. The tests were not made in winter, but it is presumed that then the consumption of mineral oil would be less. As a result of the tests, the Paris-Lyons-Mediterranean Company abandoned in 1891 the use of mineral oil and adopted exclusively colza oil with an addition of 10 per cent. of shale oil, the latter having the advantage of thickening less at a low temperature. The Author estimates that in round numbers his company spent in 1890 £640,000 in coal for the traction of their trains, and used 766 tons of lubricants. If mineral oil had been used in place of colza oil, £64,000 more would have been expended on coal and £12,250 less on oil, thus justifying on the side of economy the choice of colza oil.

From the experiments made on the resistance of the front and rear portions of coal trains, it was found that the front portion had a resistance of 20 per cent. higher than the rear portion, from which fact however the Author sees no practical conclusion to draw. In comparing the resistances of a coal-wagon having a transversal surface of 20 square feet, and a covered wagon with a

surface of 46 square feet, it was found that the covered wagon had a resistance of about 16 per cent. higher than the coal-wagon at a speed of 19 miles an hour, increasing to about 30 per cent. at a speed of 38 miles an hour. With regard to the comparison of two- and three-axled carriages, it was found that the resistance to traction per ton on the rails was always less for three axles than two, and consequently all the new carriages are mounted on three axles.

J. A. T.

The Rowan System of Steam-Tramways in France.[1]

By P. Guédon and — L'Huillier.

(Revue générale des Chemins de fer, August, 1894, p. 65.)

This system consists of an engine and car combined, and four of these engine-cars were tried for the first time at Paris in 1889, during the time of the Exhibition, on the line from the Trocadero Station to the Palace; afterwards they were taken to Boulogne, and have since then regularly worked the "Auteuil-Boulogne" line, giving general satisfaction. On week-days three of the engine-cars are in use, and the departures take place every quarter of an hour. At certain times of the day a second car is attached to each engine-car. The total number of journeys made daily is 122, 38 of these being made with an additional car. The total length of the line is 1·61 mile, and the time occupied by each journey is from twelve to fifteen minutes; including the stops, the speed attained is from 7½ to 10 miles an hour, the latter figure being the maximum speed allowed. The cars stop at eight fixed points, situated generally at the road junctions, and do not stop at intermediate points. On Sundays and holidays four cars are used, and a twelve-minute service is brought into operation. The cars are turned at each terminus by means of traversing an American triangle. The receipts, which amounted formerly to an average of £11 4*s.* per day by the use of horse traction, have risen to £18 12*s.* The line is nearly level with the exception of a short length of 160 yards, which has a gradient of 1 in 29. On part of the line Vignoles rails are used, the rest of the permanent way being laid on the Marsillon type. The gauge is 4 feet 8½ inches.

The framework of the car is formed of two longitudinal iron beams with cross-bars at each end. The cars do not carry passengers on the roof, but have two platforms at each end which together carry twenty-one passengers, the inside of the car carrying twenty-two passengers. At the front the car rests on the frame of the engine by means of two springs; at the back the car is supported by a bogie, which, owing to the lightness of the

---

[1] Minutes of Proceedings Inst. C.E., vol. lxxix. p. 108.

car, has only one axle. The total length of the car is 30·5 feet, the width 6·56 feet, and the height of the frame 7 feet. The distance from the axle of the frame to the axis of the bogie is 18·63 feet.

All the engines are on four wheels coupled; the diameter of the wheels is 24½ inches, the wheel base is 5·05 feet, and the weight of the engine without fuel or water is 5 tons 8 cwt. The frame is composed of two plates of 0·39 inch thickness on the inside of the wheels and connected at their extremities with plates of the same thickness. The connection of the car frame with the engine is so made that by raising the car a little the engine can be drawn out easily and can then be repaired and cleaned. The boiler is cylindrical, and consists of two portions bolted together. There are 131 tubes, which have an external diameter of 1·48 inch, a thickness of 0·196 inch, and a length of 22·24 inches; the water circulates through the interior of the tubes. The total heating surface is 112·48 square feet, and the amount of water evaporated attains 198 gallons per hour when a blast is used. The boiler plates are of iron, with a thickness of 0·59 inch; the grate surface is 4·84 square feet; the bars, which are of cast-iron, have a thickness and spacing of 0·39 inch. Coke of the best quality is the fuel, and the fire is charged with beds of about 12 inches depth.

The volume of water contained in the boiler, the level being 0·39 inch above the last range of tubes, is 88 gallons, and of steam 9·53 cubic feet. The feeding appliances consist of a pump and injector, the latter being on the "Koerting" system, and has a discharge of about 8·8 gallons per minute; by the use of this system water can be supplied to the boiler at a high temperature, which the Authors state is a quality absolutely indispensable in the Rowan engines. There are two safety-valves, one on Adam's system and the other on the balance type, each having a diameter of 1·8 inch.

The cylinders are horizontal, and have a diameter of 6·53 inches, and the length of stroke is 13·38 inches. The theoretical maximum tractive force is 2·08 tons, and the mean force 1·35 tons. The transmission of the movement of the piston to the wheels takes place by means of a side lever, the arms of which are in the relation of 3 to 2, on the Wintherthur system. At the speed of 7·45 miles, with a pressure of 113 lbs. per square inch and an admission of 30 per cent., the work developed is about 39 HP. The amount of coke required in these engines is about 8·16 lbs. per mile, and about 12·77 lbs. per mile when an extra car is attached. A condenser is placed on the roof of the car, consisting of twenty-four rows, each containing nine tubes of 0·787 inch diameter and 19·68 feet in length; the height of each row is 10·9 inches, and the total surface exposed to the air is about 860 square feet.

An engine of another type has also been brought into use, the boiler of which is formed of two vertical bodies connected at their upper portions by a horizontal neck of the same diameter as the

vertical bodies. There are two fire-boxes and chimneys, but only one steam-gauge, regulator, and water-level tube.

A full description of the engines, engine-house, &c., with two plates, is given.

J. A. T.

The Properties of Coal as Fuel for Steam-Boilers.

By M. Schmidt.

(Mittheilungen aus der Praxis der Dampfkessel- und Dampfmaschinen-Betriebes, 1894, pp. 447 *et seq.*)

Some manufacturers usually require their coal merchants to furnish material which shall contain (1) a certain proportion of lumps, (2) a small proportion of ash, (3) a certain percentage of volatile material, usually about 20 per cent. Accordingly the pit-owners only guarantee these three elements.

The moisture contained in the coal is of considerable importance, and also its freedom from stones and slate; but perhaps the number of heat-units generated by complete combustion is the best measure of the value of a coal. Lump coal has a greater calorific value than small coal or dust, and the Author gives comparative figures. It is proposed that lump coal be defined as that which is retained on a sieve of 1·4 inch mesh.

All coal—even coal fresh from the mines—contains a certain amount of moisture, from 1 per cent. to 6 per cent., which is not altogether unfavourable for combustion; the percentage of moisture must not, however, fall outside certain limits. Some railway companies pay only for the dry coal, and make a moisture test on all coal received, rejecting that in which the moisture exceeds 7 per cent.

The quantity of ash and cinder is of great importance; not only has this to be paid for and transported, but on being put into the furnace it hinders combustion and adds considerably to the work of the stokers. The railway companies specify 6–8 per cent. of ashes and cinders, pay 0·5 franc per ton for 1 per cent. less, and deduct 0·5 franc per ton for 1 per cent. more, and reject any delivery containing more than 10 per cent. ash and cinders.

The proportion of volatile components influences the ease of kindling the coal, and the quickness with which it burns. In sugar works 20–22 per cent. of volatile components is demanded. If the draught is strong 15 per cent. may be sufficient, while with weak draught 25–28 per cent. is required. A coal containing too much volatile material burns too quickly without giving up usefully the heat due to its combustion. A mixture of two coals containing respectively too little and too much volatile material should be rejected. The wider commercial use of calorimeters is recommended, a coal giving less than the specified number of calories to be rejected.

The fusibility of the clinker is an important point to be considered, the Author stating from his own experience that coal which, in a lightly worked boiler with weak draught, gave no fused clinker, in a hard forced boiler with strong draught gave a considerable quantity of clinker.

A specimen form of contract for coal is given at the end of the Paper.

A. S.

A New Form of High-Speed Steam-engine.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1894, p. 983.)

This high speed steam-engine, made by Ducommun, Mühlhausen, has one horizontal cylinder in which two pistons work. The steam is admitted to the cylinder between the two pistons, drives them outwards, and is exhausted during the return stroke of the pistons. The motion of each piston is communicated through a beam and connecting-rod to a shaft below the cylinder. The two cranks are exactly opposite.

In consequence of this arrangement the centre of gravity of the moving parts remains always in the same position, and though the two connecting-rods are not in the same plane, the momentum of the moving parts is practically eliminated.

A. S.

Pitting in Steam-Boilers. By M. Olry.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1895, p. 9.)

It has long been well known that very pure and soft feed-water may, under certain conditions, be dangerous to boilers. The plates subjected to this form of corrosion have sometimes almost exactly conical pits, but usually the form of the pits is spherical. While this corrosion is going on the pit is filled, sometimes with a brown, sometimes with a yellow or red powder. Since the volume of this powder is greater than that of the metal from which it is derived, it forms a rounded elevation above the surface of the plate, which is often covered with a tough skin. In one case the analysis of the powder gave the following percentage composition:—Oxides of iron 86·26, water 0·59, fats and organic substances 6·29, calcium salts 4·52, silica, alumina, &c., 2·34. In another case the skin had the following composition:—Calcium carbonate 38·0, magnesium carbonate 8·7, calcium sulphate 12·8, silica 8·2, oxides of iron 32·3.

The depth of the pitting varies; sometimes the corrosion quite pierces the plate. This corrosion is found generally in places

where the circulation is feeble, in boilers lying idle and which have not been completely emptied; in empty boilers in connection with neighbouring boilers when the stop-valve is not perfectly tight, and steam even in small quantities is allowed to enter; but seldom on plates which are constantly below the water-level.

Pure feed-water which has been long boiled in order to expel the dissolved gases is harmless. The experiments of Messrs. Scheurer-Kestner and Meunier-Dollfus show that the corrosion is due to the dissolved gases, of which oxygen and carbonic acid are the most prejudicial. Professor Crace-Calvert has shown that iron is not attacked by dry oxygen and carbonic acid, nor by moist carbonic acid—weakly by moist oxygen—but is rapidly oxidized by a mixture of moist oxygen and carbonic acid.

It seems that the greater the proportion of carbon in the metal the better it can resist this corrosion; wrought-iron corrodes easier than cast-iron.

Certain substances—soda, potash, borax—added to the water diminish this dangerous property. As regards the influence of the temperature of feed-water, it may be mentioned that where a feed-heater is used the corrosion of the feed-heater is either very small or non-existent, while the boiler is nearly always quite free from corrosion.

A number of precautionary measures, which must be carefully attended to if pitting is to be avoided, are given at the end of the Paper.

A. S.

Experiments on the Steam-engine Condenser. By C. Compère.

(Mémoires et Compte-rendu des travaux de la Société des Ingénieurs Civils, October 1894, p. 551.)

These experiments were made by the Author at Creusot, in order to determine how far condensing could be advantageously used where the supply of condensing water is limited or expensive. They tend to show that condensation may be used with a comparatively small amount of water injected, and therefore with a comparatively high temperature of condensation, without diminishing the economy of the engine seriously as compared with its performance when using an unlimited amount of injection-water. For instance, the injection-water being at 50° F., whereas condensation took place at 77° F. with a consumption of 16·3 lbs. of steam per HP. per hour, the use of only half the quantity of injection-water resulted in raising the consumption to 17·6 lbs. per HP. per hour with a temperature of condensation of 105° F. The tests varied in duration from 8 to 10 minutes, and during each test the speed of the engine and the temperature of the water pumped from the condenser were quite constant, the flow of injection-water being also constant. The boiler being used for other purposes besides that of supplying steam to the engine

under test, the supply of steam was ascertained by the calorimetric method, based on the increase in temperature of the injection-water. Previous experiments had shown that the steam carried water with it to the extent of 4 per cent. Diagrams were taken from both steam-cylinder and air-pump.

The steam-engine was a single cylinder Corliss engine with a single-acting air-pump, whose plunger was formed on a prolongation of the piston-rod. The steam-cylinder was 22 inches in diameter with 48 inches stroke; the air-pump plunger 10·5 inches diameter; the number of revolutions about 55 per minute.

The results of the tests are tabulated and are also expressed graphically in curves, whose abscissas are the temperatures of condensation. One result that appears is that by reducing the temperature of condensation too low the consumption of steam may be increased. In the experiments in question, with condensing water at 50° F., the minimum consumption of steam was reached by condensing at 72½° F. If more injection-water was used so as to bring the temperature lower than that, the result was to raise the pressure in the condenser and diminish the economy of the engine.

C. F. F.

Trials of a 300-HP. Gas-engine using Power-Gas.

(L'Industrie Électrique, vol. iii. p. 532.)

The gas-engine was of the Simplex type made by Matter & Co. of Rouen, and was used to drive the Pantin mills.

The gas in this installation was made in producers of the Buiro-Lencauchez system. The Author states that with gas made in these producers this engine has given 320 I.HP., whereas with ordinary lighting gas the I.HP. would rise to 450.

The cooling arrangements were such as to enable the engine to run continuously, and the trials in question lasted some 194 hours. During this time, 19 tons 15 cwt. 2 qr. of rough coal were consumed in the gas producers. The engine was, during the trial, driving the milling machinery, and by care a constant load was obtained corresponding to a mean I.HP. of 280. This gives a consumption of fuel of 0·81 lb. per I.HP. The quantity of circulating water needed was 1,340 gallons per hour in the water-jackets, and 660 gallons in the gas-washers; in all 7·15 gallons per I.HP. hour.

The trial was repeated after an interval of three months, and the figures obtained were practically the same.

The Author concludes: 1st. That the quantity of gas produced per lb. of coal varies from 64 cubic feet to a maximum of 80 cubic feet; 2nd. That the calorific power of the gas varies between 34 and 42 calories per cubic foot whatever coal be used; 3rd. That the best and most economical explosive mixture corresponds to a consumption of from 50 to 70 cubic feet of this gas per I.HP.

R. W. W.

A Competitive Trial of Flue-heated Coke-Ovens.

By A. Hüssener.

(Stahl und Eisen, 1894, p. 1105.)

This memoir contains the report of a trial of two groups of coke-ovens working upon the same coal and as nearly as possible under identical conditions. Each group included thirty ovens, one being on the Otto-Hoffmann system with vertical heating flues and air-regenerators at the Germania Pit of the Gelsenkirchen Mining Company at Marten in Westphalia, and the other on the Carvès-Hüssener system with horizontal flues at the works of the Coal-distilling Company at Bülmke. The capacity of the former kind of oven is about 15·9 per cent. greater than that of the latter. The coal used was the same in both cases, namely, washed slack from the Germania Mine, which is known for its good coking quality. The trial began at 6 A.M. on the 7th of August, 1893, when the whole of the ovens were charged, and terminated with their drawing at the same hour on the 18th of August, when each oven had carbonized nine charges, the time of burning being limited to forty-eight hours in every case. The product was divided into coke of blast-furnace quality, soft, or imperfectly carbonized coke, and breeze, the former being sent off by railway to the Rolandshütte furnaces at Weidenau, near Siegen, where the comparative merit of the two kinds when applied for iron-melting purposes was determined. At intervals during the trials the temperature of the flues, both at top and bottom of the ovens, was determined by Prinsep's method, with alloys supplied by the Frankfort Gold and Silver Refinery. The trials were conducted under the inspection of controllers appointed by the competing companies.

The details of the observations, which are very voluminous and are given in full, cover twenty closely printed pages, the general results being summarized in the following Table, in which G II. signifies the Otto-Hoffmann, and K. D. the Carvès-Hüssener oven :—

——		G. II.	K. D.
Coal charged	tons	954·94	932·53
Water in coal	per cent.	10·81	12·06
Coke drawn	tons	733·64	660·98
Water in coke drawn	„	46·73	4·13
Total coke (dry)	„	686·91	656·85
Proportional yield of dry coal	per cent.	80·65	80·10
Blast-furnace coke (dry)	tons	609·89	616·21
Soft-burnt „ „	„	77·03	40·65
Water in blast-furnace coke	per cent.	6·35	0·63
„ soft-burnt coke	„	6·49	0·57
Proportion of blast-furnace coke (dry)	„	71·61	75·14
„ „ soft coke (dry)	„	9·04	4·96

The total weight of coal charged in the K. D. oven was 31·67 tons dry weight less than in G II. This was due to short filling during the last three days of the trial, owing to deficient supply of coal, the charges which were at first 6·18 tons per oven having during forty-five turns been reduced to 5·87 tons. The Otto-Hoffmann ovens averaged 6·46 tons per charge, or 9·79 per cent. less than the 7·16 tons that they should have contained, supposing them to be filled to the same extent as those of Hüssener, their cubic capacity being about 15·9 per cent. larger. This insufficient utilization of the coking space is, in the Author's opinion, due to the impossibility of getting a sufficiently high temperature at the ends of the oven on the Otto-Hoffmann system.

The temperature determinations in the flues show that the heat is very uniformly distributed in the Hüssener ovens, the observed range being from 1,100° C. to 1,320° C. between the coolest and the hottest parts respectively, or from 175° to 245° more than the corresponding positions in the Otto-Hoffmann ovens, where the highest recorded observations are 1,100°, and the lowest below 900°, but the bottom flues are very much hotter (up to the melting point of wrought iron, or 1,600°).

The chemical and physical properties of the two classes of coke were determined by Dr. Thörner of Osnabruck to be as follows:—

—	K. D.	G. II.
Ash per cent.	9·20 to 9·25	8·9
Total sulphur	1·31 „ 1·44	1·98 to 1·85
Specific gravity of solid coke	1·8722 „ 1·8939	1·8684 „ 1·8726
„ „ of porous coke	0·9526 „ 0·9671	0·9124 „ 0·9189
Porosity.—Volume of pores per 100 grams of coke	50·2 „ 52·2 cubic centimetres	55·4 „ 56·1 cubic centimetres
Volume of solid per 100 grams of coke	53·2 to 52·8	53·5 to 53·4
Cubic volume per kilogram of coke	1,034 „ 1,050	1,089 „ 1,095
Moisture per cent. as received at furnace	2·515	5·139
Moisture per cent. after two days' rain	4·50	9·50

In the smelting trials which were made between the 18th and 29th of August, 1893, the blast furnace, which was then making dull white forge-iron, was burdened for grey foundry-metal, and when brought into proper working condition was supplied with K. D. coke for six days, during which time, the burden being kept unchanged, 448·4 tons of close grained foundry-pig were produced with an expenditure of 409·75 tons of coke, or 0·914 ton per ton of metal. The fuel was then changed to G II coke, which was used for five days longer, when the experiment was discontinued. During this second period the make was 384·96 tons with 345⅛ tons of coke, or 0·897 ton per ton of metal, showing a con-

sumption of 1·7 per cent. less than with K. D. As, however, the working of the furnace was sensibly less regular in the second period than in the first, the manager of the works considered that for smelting-purposes the K. D. coke was to be preferred.

H. B.

Contract Trial of the "Olympia." By R. E. Carney, U.S. Navy.

(Journal of the American Society of Naval Engineers, 1894, p. 241.)

The "Olympia" is a steel twin-screw protected cruiser, of about 5,500 tons displacement, built and engined by the Union Iron Works, San Francisco. The contract price was £359,200 with a premium of £10,000 for every quarter knot in excess of 20 knots during a four hours' trial. The protective deck is 2 inches thick on the flat, 4¾ inches on the incline in the machinery space, and 3 inches outside these limits; there are four 8-inch breech-loading guns mounted in pairs in barbettes forward and aft, and ten 5-inch quick-firing guns on the main deck. There are four 6-pounders on the superstructure deck and ten on the berth deck, and six Howell torpedo tubes. The dimensions are as follows:—

Length between perpendiculars	340·0 feet
„ over all	344·0 „
Beam, extreme, at L.W.L.	53·0 „
Draught, mean	21·55 „
Displacement at this draught, in tons	5,872·0
Coefficient of displacement	0·52
„ midship section	0·886
Prismatic coefficient	0·587
Metacentric height	2·087

The engines are of the three-stage compound type driving twin screws. The engine-framing consists of one ⅄-frame at the back of each cylinder and a pair of forged steel columns in front.

The ⅄-frames are built up, having wrought-iron side pieces secured to a cast-iron body piece which carries the cross-head slide, and to which the backing slides are bolted. Both ⅄-frames and columns are secured to manganese bronze bed-plates. The cylinders are 42 inches, 59 inches, and 92 inches diameter respectively, and the stroke is 42 inches. The propellers are manganese bronze with three blades. They are 14 feet 9 inches diameter and 19 feet pitch. The developed surface is 68 square feet. The blade tips were submerged when running to a depth of 83 inches. There are four double-ended and two single-ended return flue boilers, the former with eight and the latter with four corrugated furnaces in each, the total grate-area is 824 square feet, and the total heating surface is 28,298 square feet, the working pressure is 160 lbs. The weight of propelling machinery with water is 1,215 tons. The displacement on trial was 5,586 tons, the

speed attained was 21·686 knots, and the revolutions were 139 per minute.

The I.HP. of main engines alone was	. . . . .	16,850
" air- and feed-pumps was	. . . .	185
" remaining auxiliaries was	. . . .	278
Total collective I.HP.	. . . .	17,313

The coal burned per hour amounted to 37,937 lbs. This is at the rate of 2·19 lbs. per I.HP. if all the machinery in operation is included, and 2·22 lbs. per I.HP. if the power of main engines and air- and circulating-pumps only are included.

Very complete particulars are given concerning both hull and machinery, and the HP. developed by each of the auxiliary engines is given separately.

S. W. B.

Contract Trial of the United States Triple-Screw Protected Cruiser "Minneapolis." By ALBERT B. WILLITS, U.S. Navy.

(Journal of the American Society of Naval Engineers, November, 1894, p. 702.)

On 14th of July, 1894, the "Minneapolis," the second of the triple-screw cruisers of the United States Navy with a displacement of about 7,387 tons, maintained for four consecutive hours an average speed of more than 23 knots on her official trial, being two knots over the contract speed. The vessel is an almost exact counterpart of the "Columbia," but has a greater boiler-power. The trial consisted of two runs over a measured course between two capes about 44 sea-miles apart.

In the "Columbia" all three screws had a pitch of 21 feet 6 inches. The diameter of the wing screws was 15 feet, and of the centre screw 14 feet. The distance between the centres of the wing screws was 25 feet 2½ inches, and they were placed 13 feet 8 inches in advance of the centre screw. The axis of the centre screw was 3 feet 3 inches below the axes of the others. The side screws turned outwards, and the centre screw was right-handed. The centre screw ran at 127·7 revolutions, the port screw at 132·9, and the starboard at 134 revolutions.

In the "Minneapolis" the pitch of the side screws was made 22 feet, the pitch of the centre and the diameter of each remaining the same as in those of the "Columbia." Although the wing screws are one foot larger in diameter than the centre, the helicoidal area is about the same in each, 53½ square feet, the centre screw having wider blades. The centre engine ran at 132·2, the starboard at 132, and the port at 133 revolutions per minute, or practically at the same speed. The centre shaft is parallel to the keel, and the wing shafts are inclined upwards at about 1 foot 11 inches in 100 feet, and outwards at about 3 feet 10¼ inches in 100 feet. This

brings the centre of each wing propeller 13 feet 5 inches forward, 3 feet 3 inches above and 12 feet 5 inches outboard of that of the centre screw. The immersion of the upper ends of the blades at normal draught is 5 feet 5 inches and 9 feet 2 inches, in the case of the wing and centre screws respectively.

The vibration of the "Minneapolis" was considerable at full speed, and was at a maximum at the bow and stern and amidships. The change of trim at full speed was 11 inches, the mean speed over the measured distance was 23·073 knots.

When proceeding at a speed between 12 and 13 knots with one wing screw only, the other two revolving freely, a helm angle of 6·5° was required to keep a straight course. The vessel completed a circle at full speed in 2 minutes 45 seconds, the diameter being about 5 lengths. The heel was less than one degree.

The weight of machinery, including water in boilers, condensers, and pumps, but exclusive of stores, heating apparatus, spare gear, tools, capstan, windlasses, steering-gear and winches, was 1,962 tons. The length of the ship is 412 feet, beam 58, draught 24, and the normal displacement 8,005. The shell-plating is generally of ⅝-inch mild steel; the protective deck consists of two thicknesses of 1½-inch nickel steel. This is increased to a total of 4 inches on the slopes over the machinery space. The lower edge of the deck is 4 feet 6 inches below the normal water-line, and it rises to 1 foot above in the centre. A cofferdam 5 feet thick, 7 feet 6 inches high, filled with compressed cellulose, extends the entire length of the ship's side above this deck. The complement is 457. The armament consists of one 8-inch, two 6-inch, eight 4-inch, twelve 6-pounders, four Gatlings, four 1-pounder guns, and four torpedo-tubes. The metacentric height is 3 feet 0½ inch. There are three sets of 3-cylinder triple-expansion engines in separate compartments. The valves are all of the single-ported piston type, there being one for the high, two for the intermediate, and four for the low-pressure cylinders. The cylinders are 42, 59, and 92 inches in diameter respectively, with a stroke of 42 inches. The total heating-surface of the main boilers is 48,194 square feet, and the grate-surface 1,456 square feet. The boilers are double-ended, with four furnaces at each end. The two adjacent furnaces on each side of each end have a common combustion-chamber. No trouble was experienced from leaky tubes, and this is attributed to the manner in which the feed-water is distributed, and to the method adopted for forcing circulation. The steam-pressure was 150 lbs. The funnels are 70 feet high from grate level. Sixteen 60-inch Sturtevant blowers supply 10,200 cubic feet of air per minute to the furnaces, at a pressure of one inch of water. The I.HP. developed by main engines was 20,366, that of main engines and air and circulating pumps 20,453, and the total developed by all the machinery, was 20,862.

S. W. B.

Mining Handbook to the Colony of Western Australia.[1]

By HARRY P. WOODWARD.

This work gives an account of the occurrence and distribution of the various gold and other deposits in Western Australia, a matter of considerable interest at the present time in view of their largely increasing gold output, which is given as 110,891 ounces in 1893, or nearly double that of the previous years. The total up to the end of 1893 is close on a quarter of a million ounces. Short reviews of the political and physical characteristics, and of the geognosy or general description of the country, are given and followed by a brief account of the geology, from which it appears that strata of nearly all ages are represented.

There are five auriferous belts in this colony, the first of which runs nearly north-south, about 200 to 250 miles from the coast, in the southern portion of the colony; and it is on this belt that Gilgarn and the Murchison goldfields are situated. The Coolgardie belt, about 100 miles to the eastward and parallel to the Gilgarn belt, extending from the Dundas Hills through Coolgardie, Ularring, to the eastward of the Murchison. On the Ashburton the belt runs north-west and south-east, but is probably the extension of the Gilgarn belt, which ends at the head of this river. The Roebourne belt strikes east and west along the north-west coast from the Nicol river to the De Grey River, disappearing beneath the sandy tableland to the eastward. The Kimberley belt strikes in a north-east and south-west direction, and is very probably the extension of the Roebourne belt, reappearing on the north-easterly side of the sandy tableland. These belts carry gold for a great length; the reefs, as a rule, are of great size, very rich, and wherever they have been tested they have proved to be good. A large quantity of stone has been crushed from the different fields, which has averaged 1 oz. to the ton of stone, whilst alluvial patches of great value are still being worked. Gold also occurs associated with pyrites along the Darling range at Kendinup, Bindoon, the Wongan Hills, and the eastern districts; it has also been found in stone at Yuin and in the alluvial form at Peterwangy at the head of the Irwin.

An account is given of each of these fields and of the most important producing localities, maps being also appended. Copper and lead are found in rich deposits in the Victoria district and also in the north-west. The most important tin ore deposits are in the 50 square miles of the Greenbushes field on the Blackwood river. Coal-deposits cover large areas in the south-west division, and have been worked to a considerable extent. The most important deposits are shortly described, and their situations shown on a map.

---

[1] The original is in the Library of the Inst. C.E.

The colony contains large deposits of iron. Antimony, zinc, manganese, mica, asbestos, kaolin and graphite deposits have also been discovered. Appendices contain some notes on legal matters connected with mining, and other hints to prospectors.

R. E. C.

Experiments on Mine-Ventilation. By R. Hausse.

(Der Civilingenieur, 1894, p. 565.)

(1) *The resistance of a mine to circulation of air* is the sum of all the frictional resistances which the air has to overcome in its passage through the mine, and of the resistances due to acceleration in consequence of sudden change of direction and section of the air passages. If Q and Q_1 are the quantities of air, and h and h_1 the corresponding differences of pressure produced by the ventilator,

$$\frac{Q^2}{Q_1^2} = \frac{h}{h_1} \quad \ldots \ldots \quad (1)$$

Accordingly the fractions $\frac{Q^2}{h}$ and $\frac{Q_1^2}{h_1}$ are constant. The quotient $\frac{Q^2}{h}$ gives a measure of the resistance. Let h_t be the total effective pressure in the ventilating shaft, h the pressure corresponding to the resistance, v the velocity of discharge of the air from the shaft, and γ the weight of unit volume of air, then

$$h_t = h + \frac{\gamma \cdot v^2}{2g} \quad \ldots \ldots \quad (2)$$

The pressure h gives a simple measure of the resistance of the mine, thus

$$h = h_t - \frac{\gamma \cdot v^2}{2g} \quad \ldots \ldots \quad (3)$$

Let h_g be the pressure required to produce a discharge of unit volume of air per second, then from (1),

$$h_g = \frac{h}{Q^2} \quad \ldots \ldots \quad (4)$$

Substituting $v = \frac{Q}{F}$ in (3), F being the sectional area of the shaft,

$$h = h_t - C\,Q^2 \quad \ldots \ldots \quad (5)$$

where C, being a constant, from (4) and (5)

$$h_g = \frac{h_t}{Q^2} - C \quad \ldots \ldots \quad (6)$$

The mine resistance h_g is completely defined by this equation, and the values obtained are comparable. The Author discusses (1) Variation of Q due to variation of the total pressure h_t, the mine resistance h_g being constant; (2) Variation of Q due to variation of mine resistance h_g, the total pressure h_t remaining constant.

(2) *Relation between the rim velocity of a fan and the pressure produced by it.*—If u be the tangential velocity at any point of a centrifugal fan, and c the relative velocity of the air along the blade, then

$$u^2 - c^2 = C,$$

C being a constant. If the fan produces a certain pressure h, assuming that there is no loss, but merely transformation of pressure into velocity, and *vice versâ*, the above relation may be written

$$h = \frac{u^2}{2g} - \frac{c^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The condition that the air should leave a centrifugal fan with minimum velocity is not expressed in equation (7). Let $\frac{v^2}{2g}$ be the head corresponding to the absolute velocity of delivery, then the fan may produce this amount of additional pressure, and the total pressure is then

$$h = \frac{u^2}{2g} - \frac{c^2}{2g} + \frac{v^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

But v is the resultant of the tangential velocity u and the relative velocity c, and for a fan with radial blades

$$\frac{v^2}{2g} = \frac{u^2}{2g} + \frac{c^2}{2g}.$$

Substituting this value of $\frac{v^2}{2g}$ in (8),

$$h = 2\frac{u^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

That is, the theoretical pressure is twice the pressure corresponding to the rim velocity.

Denoting by h_1 and h_2 the pressures due to the centrifugal and tangential effects respectively, and by h_o, the total pressure produced by the fan,

$$h_1 = \frac{u^2}{2g} - \frac{c^2}{2g},$$

$$h_2 = \frac{u^2}{2g} - \frac{u_1^2}{2g},$$

where u_1 is the tangential velocity of the air as it leaves the fan. Also

$$h_e = 2\frac{u^2}{2g} - \frac{v^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

That is, the head produced by a fan is equal to twice the head due to the tangential velocity of the rim less the head due to the velocity of delivery of the air. This equation is fundamental, and applies to all kinds of fans, open, as well as those with vortex chambers.

(3) *Pressure-anomaly.*—From the above laws of ventilation, for the supply of a definite quantity of air Q through a mine a certain definite pressure is required, the pressure being equal to the difference of pressures at the supply and discharge shafts. But with the wider proposition: "For the supply of a certain quantity of air Q for a mine, a certain pressure is required, whatever be the type of ventilator used," experiments are not in agreement. At the royal coal mines, Plauen'schen Grunde, near Dresden, two Guibal fans with vortex chambers, and two open Winter fans are used. The Guibal fans are 23 feet diameter, and have eight wings 5 feet 9 inches wide, and supply air to the Döhlen and Carola shafts. One of the Winter fans is 6 feet diameter, 1½ foot wide, and supplies air to the Albert shaft; the other is 9·8 feet diameter, has sixteen wings 1½ foot wide, and supplies air to the Oppel shaft. The quantities of air per second reduced to a pressure head of 1·44 inches of water are 9·19, 9·43, 12·03, and 10·32 cubic metres for the Döhlen shaft Guibal fan, Carola shaft Guibal fan, Albert shaft Winter fan, and Oppel shaft Winter fan respectively. From these figures it is seen that the Albert shaft Winter fan circulates a considerably greater quantity of air than the three others. The Author discusses at length the influence of natural ventilation in the four cases, and concludes that it throws no light on the cause of the greater circulation in the Albert shaft with the Winter fan. He then considers the possibility of the type of fan influencing the quantity $\frac{h}{Q^2}$. The following experiments on this point were made:—Two ventilators of quite different types were made to drive air against different but quite definite resistances, the ventilators acting in turn as blowers and exhausters. The ventilators used were a Roots blower and a Cappell centrifugal fan. The dimensions of the ventilators and the method of carrying out the experiment are described at length, as are also the observations made. From the experiments it is deduced that two ventilators differing in size or construction, which are used to circulate air against the same resistance, require for a given quantity of air circulated per unit of time, not the same but different pressures.

Let h_w be the real effective pressure, h_t the observed effective pressure, and h_a the pressure anomaly, then

$$h_a = h_w - h_t.$$

The Cappell fan when blowing produces the smallest pressure-anomaly, but when exhausting its pressure-anomalies are much greater.

The Paper is accompanied by numerous Tables and three plates of illustrations of the fans experimented on.

A. S.

Winding-ropes in deep Belgian Collieries.

(Comptes Rendus mensuels de la Société de l'Industrie Minerale, Sept., 1894, p. 245.)

Messrs. A. Harmegnies Brothers, of Dour, Belgium, have manufactured flat drawing ropes for new deep winnings in the Mons and Charleroi districts. The largest of these, made for the Sainte Henriette, or No. 18 pit of the Société des Produits at Flenu, are intended to lift a load of 6½ tons, made up of 3½ tons weight of cage and six tubs and 3 tons net load of coal, from a depth of 1,200 metres (3,937 feet). They are made of Manilla aloe fibre of a flat section, with ten strands tapering in breadth from 420 millimetres at the large end to 220 millimetres at the small end, and in thickness from 49 to 29 millimetres. The average weight per metre is 11 kilograms, giving for the length of 1,350 metres a weight of 14·85 tons for each rope. The working strain will be 90 kilograms per square centimetre at the thick and 110 kilograms at the thin end. These are the first ten-stranded ropes that have been made in aloe fibre. The winding engines constructed in the shops of the Société des Produits have cylinders 1,100 millimetres in diameter and 2,000 millimetres stroke, and are intended to be worked with steam at 4 atmospheres boiler-pressure, bringing the load from the bottom of the mine to the bank in 65·4 revolutions, the radius of effort on the rope reels varying from 1·62 metre empty to 4·22 metres when filled. The moment of the load varies from 17·166 kilograms at starting to 405 kilograms on the arrival of the cage at bank. The steam-consumption will be 248·52 cubic metres, or 465 kilograms per journey. The working life of the ropes will be about twenty-four months. Flat steel ropes by the same makers are in use at the Providence pit at Marchiennes au Pont near Charleroi. These are made of eight parallel four-stranded ropes tapered by reducing the number of wires in the strand from twelve to eleven and ten, according to position, the diameter of the wire, which is of crucible cast steel, of a tensile strength of 89 tons per square inch, being kept constant at 2 millimetres throughout. The breadth of the rope varies from 200 millimetres at the thick to 170 at the thin end, and the average weight is 12·25 kilograms per metre. The winding engines of 2,000 HP. are similar in dimensions to those noticed above, and draw a gross load—12½ tons; 6½ tons for the cage and twelve tubs and 6 tons of coal—from a depth of 950 metres (3,117 feet). Owing to the small diameter of the shaft only

single-tub decks can be used in these collieries, so that ten- and twelve-deck cages are required in order to be able to command a large output during the shift while running the engines at a proper working speed. The life of the ropes is about twelve months.

H. B.

The Relation between Composition and Refractory Characters in Fire-clays. By H. Jochum.

(Zeitschrift des Vereines deutscher Ingenieure, 1895, p. 53.)

The Author, in a review of the different kinds of natural materials used for fire-resisting purposes, classifies them into three groups, under the names of basic, semi-basic and acid substances. The first class comprises, in addition to lime, dolomite, magnesite and bauxite, all plastic clays containing when calcined not less than 30 per cent. of alumina, and the non-plastic shales of the coal-measures in Bohemia, Silesia and Saarbrücken, which contain up to 45 per cent. of alumina. The semi-basic includes all so-called lean clays, with less than 30 per cent. of alumina, down to binding sands, in which the proportion of silica in mechanical intermixture may be as much as 95 per cent., while the acid class includes quartz in all forms of sand, quartzite, ganister, &c., up to the typical form of the pure mineral in rock crystal.

The first attempt to establish a relation between the composition of fire-clays and their fire-resisting properties was made by Dr. Bischof of Wiesbaden, who formed a scale of fusibility with seven kinds of clays in current use in Germany by exposing them to the highest heat attainable in a specially constructed blast furnace, the results being classified in the following order, No. 1 being the most refractory :—

1. Fire-clay of Saaran in Silesia.
2. China clay of Zettlitz.
3. Fire-clay of Andenne, Belgium.
4. „ „ Mulheim on the Rhone.
5. „ „ Grünstadt in Rhenish Bavaria.
6. „ „ Oberkaufungen, near Cassel.
7. „ „ Niederpleis on the Sieg.

At the time when these experiments were made the two principal constituents of fire-clay—silica and alumina—were supposed to be infusible, and from the relation of these substances to the other fluxing bases, as determined by chemical analysis, Dr. Bischof proposed to express the refractory character of a clay by a numerical coefficient F in the following manner :—

$$F = \frac{a}{\frac{b}{a}} = \frac{a^2}{b},$$

a being the ratio, in equivalents, of alumina to that of the other bases, and *b* that of the alumina to the silica.

This formula, which agreed with the original scale, gave very unsatisfactory results when applied in other instances, as did also a modification proposed by the late Dr. Seger, namely—

$$F = (a + b)\frac{a}{b},$$

and the subject was further investigated by the last-named observer in a series of experiments published shortly before his death in 1893. In these, mixtures of chemically-pure alumina and silica, in varying proportions from equal equivalents (corresponding to 55 alumina to 60 silica) up to $Al_2O_3\ 26SiO_2$ (2·3 alumina to 97·7 silica), were tested for fusibility against mixtures of China clay and fine sand in similar equivalent proportions with a small quantity of felspar added to keep the alkalies constant. The tests were made in a Deville blast furnace fired with gas-retort carbon, the supports used being small crucibles of magnesia or chromic iron ore, which were lined with a thin coating of highly alcined alumina to prevent any fluxing-action on the test-piece. The results were measured by the investigator's well-known standard pyrometric cones. The results showed the most refractory mixture to be $Al_2O_3\ 2SiO_2$ (31 alumina, 69 silica) represented by No. 36 of the scale, or about No. 35 when a small quantity of alkali was added in felspar, those containing more silica becoming more fusible up to $Al_2O_3\ 16SiO_2$, which melted at No. 29. Beyond this the melting-point was raised, as the alumina diminished, without, however, reaching to that of the first-named mixture, as pure rock crystal melted at No. 35. The result was confirmed by trials with the shale of Rakonitz, about the nearest natural equivalent to $Al_2O_3\ 2SiO_2$, which was unchanged at the melting-point of quartz, and was only exceeded in refractory proportion by chromic iron ore.

As a result of the evidence collected, the Author concludes that the application of chemical analysis in estimating the refractory character of fire-clays is only of a limited kind, and that physical properties, notably the character of the silica present, whether combined or as free quartz or sand, and the grain of the latter, are of more importance in determining their value.

H. B.

Blast-furnace Construction and Working in Upper Silesia.

By A. Gouvy.

(Bulletin de la Société de l'Industrie Minérale, 1894, p. 363.)

The production of pig iron in the Upper Silesian coal-field, amounting to about 465,000 tons, is attended with considerable difficulties arising from the friable nature of the coke, and the inferior quality of the local brown iron ores, which are mostly small and wet, besides containing zinc in such quantity as to require special arrangements for cleaning the waste gases from dust and zinc oxide held in suspension, before they can be applied as fuel, especially in those cases where regenerative brick stoves are used for heating the blast. The newest developments in this direction are to be seen in the furnaces Nos. I and IV at Friedenshütte,[1] the latter being represented in Plate XIII accompanying the memoir. These furnaces, of 8,400 feet capacity, 59 feet high, 19¾ feet in diameter at the boshes, 10 feet in the hearth, and 14½ feet at the throat, are constructed on Büttgenbach's principle; the stack, a single shell of fire-brick, tapering in thickness from 32 inches at the bottom to 28 inches at the top, with a cast-iron base ring, carried by seven cast-iron standards, being placed within a framework formed of four tubular iron pillars 75 feet high and 35 feet apart, stiffened at intervals by horizontal girders, tie-rods and angle-brackets to carry the charging and gas-collecting apparatus which are unusually large and heavy, but no part of their weight rests upon the brickwork. The gases throughout the district are almost invariably collected by the Langen apparatus having a conical charging hopper stopped by a telescopic bell with a water seal on the central gas-pipe, the whole arrangement being outside the furnace, leaving the latter, when the bell is lifted, perfectly free, when it becomes necessary to clear out the accretions of zinc oxide at the throat. At Friedenshütte the gas-pipe, of 8¼ feet inside diameter, rises to a height of 42 feet above the furnace top to give room for an inclined pipe leading to the vertical downcomer, as a horizontal one would be very speedily blocked up by the deposited dust. Between the collecting-tube and the main gas-conduit are interposed two groups of gas-tubes standing in a shallow tank forming a water-seal at the bottom of each tube. The first group includes the downcomer and two other circular tubes, each 65⅔ feet high and 8¼ feet in diameter, and the second five more of rectangular section, 7½ by 10 feet and 46 feet high, made of sheet iron 4 millimetres thick, stiffened externally with diagonal straps of iron angle-bar, and divided by an internal partition, extending nearly to the top, into two parts, giving a passage of 32 square feet and 92

[1] There is a better figure in Wedding's Paper, Transactions of the American Institute of Mining Engineers, vol. xix. p. 340, from which some of the dimensions are taken, but it gives no description of the gas-cleaning arrangements.

feet long for the gas in each tube. The total length of gas-way in the combined apparatus is 660 feet, and the volume nearly 25,000 cubic feet, or three times that of the furnace to which it is attached.

The blast is furnished by a horizontal compound engine with two blowing cylinders 7 feet 4½ inches in diameter and 5 feet 7 inches stroke, giving, at 25 revolutions per minute, 20,800 cubic feet of air at a pressure of 6 lbs. per square inch. The weight of the engine, including the condenser, but without the fly-wheel of 41 tons, is 200 tons, or 100 tons less than that of the direct-acting vertical engines of the Cleveland or Seraing pattern of about the same capacity which are common in the district.

In consequence of the improvements in the gas-cleaning arrangements fire-brick stoves, which were formerly considered to be unsuited to furnaces smelting ores containing zinc, are now becoming general in Upper Silesia. These are mostly Lürmann's and other modifications of Cowper's system. At Friedenshütte three Cowper stoves, 66 feet high and 23 feet in diameter, with 48,400 square feet of heating surface, supply blast at 1,450° F., to two furnaces which together burn 240 tons of coke per day. The filling of these stoves is arranged on a plan due to Mr. Martin Bœcker; the checker-work is carried on brick arches, instead of iron girders, and the rectangular gas-passages increase in size outwards, being 4 inches square at the circumference, and only 3 inches near the centre. 620 tons of 3-inch rectangular brick and 130 tons of moulded pieces are required for each stove. These are made of three different qualities, varying in price with their fire-resisting power from 21*s.* to 50*s.* a ton, the total cost of the filling being about £1,700 per stove. These stoves have been at work for 5½ years without requiring to be stopped for repairs, or to clean out deposits in the passages—a result which is mainly attributed to the careful preliminary cleaning of the gases.

The blast-furnace boilers at Friedenshütte are mostly of the water-tube kind, with a special system of safety firing which has been adopted since the disastrous explosion in July, 1887, when a range of twenty-two boilers was destroyed at one time. In this the fire-grate is replaced by a fire-brick checker-work about 5½ feet deep, which keeps at a red heat and ensures the immediate ignition of the mixture of gas and air, even after a stoppage of seven or eight hours. It has also a further advantage of improving the evaporative power which has been raised from 1·64 lbs. to 2·87 lbs. of water per square foot per hour.

The ores smelted are mostly derived from irregular deposits in dolomite, contain from 35 to 40 per cent. of iron, 20 to 25 per cent. of silica, 3 to 4 per cent. of manganese, 0·2 to 3·0 per cent. of lead, and 0·5 to 4·0 per cent. of zinc, when dried at 100° C.; but as delivered the amount of water varies from 20 per cent. in summer to 30 per cent. in winter, with a corresponding diminution in the metallic yield to 24 per cent., so that an admixture of richer materials is necessary to render them fit for smelting. This is supplied

in the form of calcined spathic ore from Austria and Hungary, magnetite from Sweden, and forge and mill cinders from the local ironworks. At Friedenshütte the charges are made in the following proportions:—

	Per Cent.
Silesian brown iron ores	70
Forge and mill cinder	25
Hungarian spathic ore	5

The flux is a ferruginous dolomite containing some zinc and about 33 per cent. of iron. The daily yield of each furnace is from 85 to 100 tons of basic pig-metal with a coke consumption of 24 to 26 cwts. per ton.[1] There is also present about 0·4 per cent. of lead, about 6 cwts. of that metal being recovered from each furnace in twenty-four hours. This filters through the joints of the hearth bricks and collects in two cross passages below the hearth bottom which are heated by a fire or gas-flame, so that the melted lead can be ladled out.[2]

The deposits in the gas-flues and dust-collectors are collected and sold to the numerous zinc smelters in the neighbourhood; the quantity produced seems to be about 2 per cent. of that of the pig-iron smelted. At Gleiwitz about 279 tons of oxide and dust, containing 57 tons of metallic zinc, have been taken from a single furnace in a year. The richest material is that taken from the top of the blast-furnace, which contains up to 70 per cent. of zinc, the deposits in the gas conduits giving 50 per cent., and those in the flues of the hot-blast stoves 39 per cent.

H. B.

On Scheibler's modification of the Basic Bessemer Process.

By E. Schrödter.

(Stahl und Eisen, 1894, p. 1097.)

Since the year 1886 the modification of the dephosphorizing process on the Bessemer converter, proposed by Professor C. Scheibler, has been adopted at several German steel works, namely, at Hörde, Rührort and Meiderich in Westphalia, and the general results so obtained are summarized in the present Paper, which was communicated by the Author to the Iron Smelters Society in Düsseldorf

---

[1] According to M. Böcker (Stahl und Eisen, 1895, p. 133) the proportion of local ores does not exceed 20 per cent. of the charge when the make attains from 100 tons to 120 tons per day with a coke consumption of 20 cwts. per ton. Formerly, when 75 per cent. to 80 per cent. of these ores were used with blast at a low heat the make was only about 40 tons, and required from 34 cwts. to 36 cwts. of coke per ton.

[2] Böcker (*loc. cit.*) states that in building, the hearth-passages for the lead are arranged by wrapping strings round the bricks or hanging them in the vertical joint surfaces. The average value of the lead and zinc saved is about 2*s*. per ton of pig-iron when 60 per cent. of local ores are used.

in November 1892. The essential point of the process is the addition of the fluxing line at two periods, instead of changing the whole quantity into the converter at the beginning of the blow. About two-thirds of the whole quantity is added at first, and the slag formed is poured off after blowing for three or four minutes, when about three-quarters of the phosphorus in the charge has been oxidized, the remainder being removed during the second period when the rest of the lime is added. The advantages claimed by the inventor of the method over the older process are:—

1. A saving of at least one-third of the lime required.

2. Shortening of the blow in consequence of the chemical reactions being more rapidly accomplished.

3. Increase of weight of metal blown at each operation.

4. Reduction in loss of iron.

5. Increased temperature during blow, producing very fluid steel.

6. More complete removal of phosphorus without increasing waste of iron.

7. Concentration of the bulk of the phosphorus in a slag nearly free from iron and therefore more valuable for agricultural purposes than the ordinary basic slag.

The Author, having received reports from several steel works where the method has been tried either experimentally or regular practice, sums up the result of their experience by way of answer to the foregoing propositions as follows:—

1. *Saving of Lime.*—The best result seems to have been attained at the Phœnix Works, where the quantity of 1·8 ton per 12-ton charge has been reduced to 1·28 ton, or nearly the one-third claimed by the inventor. In other cases, however, the saving has been less, ranging from 12 per cent. to 19 per cent.

2. *Shortening the blow.*—This has not been realized, but on the contrary the time required for each operation has been lengthened by an amount said to be unimportant in some instances, and in others from three minutes to five minutes; as the time saved by the more rapid progress of the actual blow is insufficient to compensate for that lost in the extra operation of turning down and raising the converter for pouring the first slag. At the Phœnix Works the difference corresponds to a reduction of the output from sixty charges of 10·8 tons each in twenty-four hours to 50, or 16⅔ per cent.

3. *Increase in weight of charge.*—It seems likely that a larger weight of iron may be used in the converter, owing to the reduced volume of lime present at any one time, supposing, of course, that the blowing power is sufficient to overcome the pressure of a heavier column. The advantage in this respect seems by the Phœnix experiments to be represented by a possible increase of the charge from 12 tons to 12½ tons.

4. *Diminished waste of Iron.*—At the Phœnix Works the waste was reduced from 3·8 per cent. to 3·3 per cent., calculated on the weight of finished ingots, or a saving of 0·5 per cent. At Friedenshütte, in Upper Silesia, it was considered to be about 1 per cent.

5. *Higher temperature during the blow.*—Opinion upon this point seems to be much divided. At Gutehoffnungshütte the first charges finished so hot that a large addition of scrap was necessary to cool the steel sufficiently to allow it to cool quietly. On the other hand, at the Rhenish Steel Works, the second addition of lime was found to have a strongly chilling effect, so that the method was only considered to be suitable for hot blowing metal, *i.e.*, high in silicon and phosphorus, while for colder blowing qualities the addition of the whole quantity of lime at once was preferable, as otherwise the finished charge could only be cast with difficulty.

6. *More complete dephosphorizing.*—In most instances where a comparison can be made, the analyses seem to show a slight reduction in the phosphorus on the finished steel by the same method, as for example, from 0·049 per cent. to 0·042 per cent. At Gutehoffnungshütte the average has been reduced from 0·061 per cent. to 0·050 per cent. At Friedenshütte the rail steel obtained by it contained 0·05 per cent. and that for other purposes 0·03 per cent. as maxima.

7. *Increased value of slag.*—This seems to be the most important result obtained by the method. At the Phœnix Works, when the whole of the lime is added at once, the average production of slag per 10·2 tons of ingots was 2·7 tons, containing 15 per cent. of phosphoric acid, and worth at 20*s.* per ton £2 14*s.* By the new method the total quantity of slag is reduced, but its value is considerably increased, as will be seen in the following Table:—

—	Quantity.	P_2O_5.	SiO_2.	CaO.	Mn.	Fe.	Value.	
							Per Ton.	Total.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	*s.*	*s.* *d.*
1st slag . .	0·725	23·79	5·17	50·89	6·16	6·54	39	28 3
2nd „ . .	1·465	16·69	3·11	47·06	5·02	19·29	22	32 3
	2·190							60 6

The difference, 6*s.* 6*d.* per cast of 10·8 tons, corresponds to about 7½*d.* per ton of ingots, and the total advantage is estimated as follows:—

		d.
I. Lime saved	0·051 ton at 11*s.* . . .	6·72
II. Diminished waste	0·0048 „ 60*s.* . . .	3·46
III. Improved value of slag		7·56
		17·74
	per ton of ingots.	

A similar advantage of 1*s.* 6*d.* per ton is estimated to be realized at Friedenshütte.

H. B.

The Harvey Process at Bethlehem, U.S.

By — LEPROUX.

(Bulletin de la Société de l'Industrie Minérale, 1885, p. 151.)

At the Bethlehem Works the face-hardening of steel armour-plates by cementation and chilling with water is carried on in furnaces in which the former plan of using moveable beds has been abandoned. The furnaces are built in pairs united by iron girders of sufficient strength to bear the weight of the arched roof of one of them. Each furnace is provided with fireplaces arranged at equal intervals along the longer sides. Bituminous coal giving a long flame is used as fuel, and there is a large working door at one end. The plate under treatment is placed upon supports in the furnace with the face to be hardened upwards. Upon this is placed a layer of charcoal dust 8 inches thick, which is covered by a second plate with the face to be hardened downwards. The outer sides of the plates and the spaces between them are carefully luted with fire-clay to prevent the air from getting access to the cementing material, and the completed pile is covered with sand. When the door is closed and luted the heat is gradually raised to about 1,700° F., and continued for eight or ten days until the metal has absorbed the necessary amount of carbon. The roof of the furnace is then removed by a travelling crane and the hot plates are transferred to a tank lined with masonry having a series of brick piers for supporting the plate at the bottom, between which are arranged lines of perforated pipes for spraying the lower face, a similar set of pipes suspended from the jib of a crane being provided for the upper face. The water used for chilling is cooled by passing through a tank containing ice and salt, both faces being treated in the same manner, the hardening effect being of course greater on the cemented side than on the back. The spraying is continued for about an hour, when the plate is removed to an oil-bath, where it remains until completely cold.

The surfaces of the hardened plates, especially when the metal contains nickel, become crusted with a hard scale of oxide which must be chipped off. The tool used for this purpose is the pneumatic chisel made for stone-dressing by the American Pneumatic Tool Company, in which a steel hammer attached to the piston of a small pneumatic engine driven by air at 45 lbs. pressure, strikes against the cutting tool held in an attachment to the cylinder in the same way as in hand-work. When in use it is grasped by the workman with both hands and moved as required, the air-supply being furnished by a vulcanized india-rubber pipe. The machine makes from 150 to 200 strokes per minute, and according to Mr. Fritz does the work of five men, but the manipulation is disagreeable, owing to the jarring action of the blow upon the hand. This is less felt in another form of the machine made by the

American Electric and Pneumatic Tool Company, in which the chisel is directly attached to the piston.

The Bethlehem armour plates are made of open hearth steel forged under a hammer of 125 tons or a press of 14,000 tons squeezing power. The latter, which is of a modified Whitworth construction, has two rams of 50 inches diameter, which can either be together or worked independently so as to allow of the forging of tapered plates without requiring special moulds. The length of stroke is 8 feet 3½ inches. The working pressure is 3½ tons per square inch, which is supplied by four pumps driven by engines of 16,000 HP. These are of a marine type of construction with cylinders 90 inches in diameter and 39 inches stroke. Steam is supplied by thirty-two Leavitt boilers at 160 lbs. pressure.

H. B.

On the Resistance to Oxidation of Iron and Steel Sheets.

By F. Menne.

(Stahl und Eisen, vol. xv. p. 41.)

The Author in a Paper read before the Mining and Smelting Society of Siegen quotes the following results of experiments upon the comparative susceptibility to corrosion of iron and steel sheets under different conditions of exposure that have been lately made by Mr. Mangold, Chemist to the Cologne-Müsen Mining Company. The materials treated were sheets 1 millimetre thick of wrought iron and mild steel with the following constituents.

	Iron.	Steel.
	Per cent.	Per cent.
Carbon	0·16	0·06
Manganese	0·24	0·25
Silicon	0·72	0·00

When pickled in strong aqua regia (three parts hydrochloric to one of nitric acid—sp. gr. 1·4), the steel was energetically and uniformly attacked. With the iron the action began slowly, becoming more rapid with the duration of the experiment, the surface produced was rough, showing signs of irregular welding.

Immersion in spring water—

	Iron.	Steel.
	Per cent.	Per cent.
Loss by two days' exposure	0·04	0·078
„ ten „ „ water changed at intervals	0·09	0·240

Heating in a muffle at a bright red heat without access of air—

	Iron.	Steel.
	Per cent.	Per cent.
Loss in 4·5 hours	18·32	32·20
„ 2 hours more	14·62	28·07

When exposed to an oxidizing flame for three days both kinds were completely destroyed.

Treatment with 1 per cent. salt solution—

	Iron.	Steel.
	Per cent.	Per cent.
Loss in 24 hours	0·037	0·128
„ 3 days	0·085	0·220

Exposure to carbonic acid (the waste gases of a spathic ore calcining kiln) and air—

	Iron.	Steel.
	Per cent.	Per cent.
Loss in 2 days	0·84	0·94
„ 4 „	1·60	1·40
„ 6 „	1·95	1·90

Exposure to air and water vapour—

	Iron.	Steel.
	Per cent.	Per cent.
Loss in 12 days	0·29	0·68

When galvanized, wrought-iron sheets are more durable than those of mild steel. The latter can be more cheaply produced and from the more uniform character of the metal have a better surface, but the zinc coating is thinner, and when it becomes unsound the plate is more rapidly corroded than is the case with sheet iron.

H. B.

Ore-Dressing and Concentration in Sweden. By P. G. Lidner.

(Transactions of the American Institute of Mining Engineers, Bridgeport Meeting, Oct. 1894.)

At the present time in Sweden, with one exception, only ores containing blende, or blende and galena intimately mixed, are subjected to mechanical dressing. Pure iron ores are still so abundant that magnetic concentration has not advanced beyond an experimental stage. Copper ores are treated by chemical processes which have superseded dressing. The ores treated contain blende and galena finely disseminated through fine grained grey gneiss, or limestone, so that in most cases one millimetre is the largest permissible size for dressing. The plant consists, therefore, mainly of slime concentrating apparatus. Continental methods are prevalent, and a large amount of hand-labour is used to effect a preliminary sorting.

The most prominent works in Sweden are at Åmmerberg, and were built in 1859–61, but have been improved from time to time. The treatment of the material is exceedingly involved, and as all the plant is on one floor the ore has to be rehandled very many times. The run of the mine is crushed and sized into two classes

above and below 20 millimetres. The larger stuff is hand-picked on two revolving tables, one with three and the other with two shelves. The clean picked blende is reduced by stone-breakers and rolls, and roasted. The picked wash ore is also calcined to soften the hard gangue and crumble the pyrites, so that these can the more easily be separated from the blende, and allowed to cool slowly. The material from the first sizing of 20 millimetres and under is further sized into six classes in two revolving screens. Of these the first five sizes are jigged, and the smallest size finer than 2½ millimetres is divided into two sizes by a hydraulic classifier and treated separately on three-sieved jigs. The burnt coarse ore is crushed by rolls, and with the middlings from the above-mentioned jigs passes to a revolving screen with 2½-millimetre holes. The whole, after removal of the slimes, is divided into five classes, and further treated on three- and four-sieved jigs. The slimes themselves are treated in Spitzlutten and Spitzkasten, which furnish the material for twenty-one double Rittinger tables, and a number of concave and convex slime-tables. In sixteen hours daily 165 tons of material are treated. The wash ore contains on an average 20 per cent. of zinc, and somewhat less than 1 per cent. of lead. The losses in concentration are brought down to 21 per cent., which is a good result considering the slight difference in specific gravity between the gangue and the blende. The concentrates contain about 38 per cent. of zinc, and 6 per cent. of ferric oxide. By the addition to these of the picked ore the percentage of zinc is increased to 42. The blende concentrates after being roasted at Åmmerberg are shipped to the Vieille Montagne Co.'s reduction works at Liége for further treatment.

At Sala the works are more modern and were built in 1880. Here galena and complex argentiferous materials are treated. Wash-ore is sorted out by hand, crushed, passed through a sizing drum with 24-millimetre holes, and the larger material again sorted by hand. All this ore is then reduced to a size under 4 millimetres and separated into five classes. Intermediate sizes are treated in jigs, and material under 1·4 millimetre is delivered to three Spitzlutten. The coarser stuff from these is dealt with in fine jigs. The overflow from the Spitzlutten passes over four Spitzkastens, and is treated on end bump tables and convex slime tables. Sixteen tons are treated daily, and are enriched from 3 per cent. of lead and 10 ounces of silver up to 20 per cent. and 46 ounces per ton. Half the lead and 60 per cent. of the silver are lost.

At Saxberg and Hellefors the intimate mixture of galena, blende and gangue cannot be hand-picked, so it is crushed at once down to 1 millimetre, and passed over Spitzlutten and Spitzkasten, and treated on a four-sieved jig, and double Rittinger tables. The results are far from encouraging, for in spite of all efforts the losses in concentration reach the high figure of 50 per cent., both of lead and zinc. At all these dressing works the fine mixed ore is reground in Schwartzmann or Heberle mills.

R. E. C.

On Bauxite. By F. Laur.

(Bulletin de la Société de l'Industrie Minérale, 1894, p. 513.)

In 1821 Berthier described a mineral containing from 66 to 70 per cent. of alumina in a hydrated form associated with silica and ferric oxide, which he named Bauxite after the locality where it was found, the old hill village of Les Baux near Arles. The first attempt to utilize it, made by Le Chatelier, either as a source of sulphate of alumina or as a refractory material, failed, the iron present rendering it too impure for the first use, while the almost unlimited power of shrinking in the kiln unfitted it for the second; and it was only after the introduction of Deville's method of making aluminium at Salyndres, that Bauxite became of industrial importance. The silica present in the mineral of Les Baux proved, however, to be a source of considerable loss in the manufacture, so that, after working for some time, its use was abandoned in 1873. In 1872 a bed, about 65 feet thick, of a soft white mineral, was discovered, in driving the tunnel of Saint Pargoire, near Villeveyrac, on the Southern Railway of France, having the following composition:—

Al_2O_3.	H_2O.	SiO_2.	Fe_2O_3.	Undetermined.
82·00	14·20	2·00	0·10	1·70 per cent.

or nearly that of Diaspore, $Al_2O_3\ H_2O$, of which mineral it may be considered to be an amorphous variety. This, from its freedom from iron and ready solubility in sulphuric acid, was very suitable for the production of sulphate of alumina, and works for that purpose were started by Augé and Co. at Oseraie near Avignon in 1875. Subsequently the process was introduced into America by Harrison Brothers of Philadelphia, who continued to use the Villeveyrac Bauxite for about ten years, until the discovery of similar deposits in Alabama and Georgia.

When worked on the large scale the new mineral proved to be notably more siliceous than the sample first examined, so that when it was attempted to apply it in the production of alumina by Deville's method of calcination, with soda to form soluble sodium aluminate, the yield proved to be unsatisfactory, and a considerable loss of alkali was experienced, owing to the formation of an insoluble sodium aluminium silicate. Further researches made in accordance with the demands of chemical manufacturers in Germany, Austria and other countries, led to the discovery at Le Luc, near Toulon, and several other places in the south-eastern departments of France, between the Rhone and the Italian Alpine frontier, of a compact red variety, containing only from 1 to 3 per cent. of silica, which, although containing too much iron for conversion into sulphate, is admirably suited for the production of alumina, for which purpose it is largely exported to Germany, about 150,000 tons having been sent away in ten years, as no mineral of a similar character has as yet been found anywhere,

except in the south of France. The pure alumina made from it ranges in price from £24 to £28 per ton, and forms the basis of the electrolytic production of aluminium as carried out at Neuhausen, Froges, Pittsburgh and elsewhere.

Although the Bauxite of different localities varies very considerably, both in composition and properties, the Author finds on comparing the returns of analyses representing the composition of thousands of tons, that there is a remarkable uniformity, from 66 to 69 per cent. in the proportion of the principal constituent, alumina, and also in that of the sum of the three principal accessories, water, silica and ferric oxide at 27 per cent., while what may be called accidental constituents, titanic and vanadic acids, &c., make up at most 3 to 4 per cent. The three varieties previously noticed may therefore be classified as follows:—

1. *Pale Bauxite.*—This is sometimes pisolitic in structure and cream coloured, but generally resembles soft chalk. The 27 per cent. of accessories is made up of water and silica in about equal proportions, iron being only present accidentally.

2. *Red Bauxite.*—This is similar in appearance to ruddle or red chalk, being of a compact or fine grained texture with a splintery fracture. The accessories are water and ferric oxide, silica being reduced to between 2 and 4 per cent. as an accidental constituent.

3. *Mixed Bauxite.*—This, the original mineral of Les Baux, from its mottled red and white colour and pisolitic structure is obviously not a single substance, but is made up of irregular mixtures of the pale and red varieties. On the large scale it contains water, silica and ferric oxide in about equal quantities, or 9 per cent. of each. The Bauxite of Styria and Antrim is of this character.

In Georgia and Alabama a fourth variety has been found, containing neither silica nor iron, which the Author considers to be an amorphous variety of hydrargillite or dihydrate of alumina, containing 27 per cent. of water. In another direction he has found examples of the total replacement of water by silica, giving rise to a basic aluminium silicate with 27 per cent. of silica, resembling a hard variety of lithographic stone. This occurs in large quantities, but has not as yet found any useful application. The whole of the water in the red variety may also be replaced by ferric oxide, giving an iron ore very similar in appearance to the concretionary alluvial mineral of Berry, and at Veyverrac the white variety is in places associated with one of a violet tint containing manganese, and no doubt other varieties will be discovered by further search. In Alabama a bauxite has been found, containing organic matter in combination with alumina, like that in the artificial colouring matters known as lakes, which cannot be used for the manufacture of sulphate of alumina by the direct action of sulphuric acid.

As the result of twenty years' experience in the working of these minerals, the Author considers bauxite to be the result of the

action of thermal waters which have deposited gelatinous alumina sometimes alone, but more generally simultaneously with gelatinous silica and other oxides; this particular phase of geyser activity having been restricted to the close of the lower cretaceous period, as all the known deposits in the south of France are on the same horizon, between the Urgonian and Cenomamien formations, *i.e.*, between the gault and the lower greensand. Mineralogically its place is midway between clay and brown iron ore.

H. B.

NOTE.—The Author's application of the name Hydrargillite differs from the ordinary mineralogical use, where it is applied to a crystallized mineral of the composition $Al_2O_3\,3\,H_2O$ containing 34·6 per cent. of water. The dihydrate $Al_2O_3\,2\,H_2O$ with 26 per cent. of water is generally called Bauxite.

The Stanley Electric Company's new Two-phase Alternating Apparatus.

(The Electrical Engineer, New York, 1895, p. 505.)

The objects kept in view by the designers of the system were (i) to utilize existing apparatus; (ii) to have only one class of plant in new stations for every variety of work, whether it were power or lighting by glow- or arc-lamps; (iii) to transmit power over long distances with simplicity.

The two-phase generator can be used on circuits ordinarily worked by single-phase machines, transformers designed for the frequency generally used (15,000 to 16,000 alternations) being perfectly adapted to the purpose; it is only necessary to combine two circuits on the switch-board. The importance of regulation is referred to, the starting and stopping of motors being especially liable to cause variation in voltage, largely on account of the heavy (so-called) "false" current.

It is pointed out that although a lower frequency than that now in use is desirable for long-distance transmission, yet the large amount of capital invested in the high-frequency plant renders it necessary to make the new apparatus run at the same in order to adapt it to existing plant. Further, a machine having a high frequency is easier to regulate. The Stanley Company, therefore, make their generators to give either 16,000 or 8,000 alternations at the same speed, the former being used in old stations, the latter in new.

The alternator has a revolving field or "inductor," formed of a steel casting having polar projections of iron laminæ. There is no winding on it. The armature, which is stationary, is formed of laminated iron, having grooves in which are placed the coils wound on formers. They can be easily replaced if burnt out without disturbing the inductor or using special tools. The wires from both armature and field are brought to a marble terminal-

board, covered by a marble slab having projections which serve to divide off the terminals into separate compartments. Arrangements are made for the insertion of fuses on this board. The armature coils can be connected in series or parallel, so as to give 1,000 or 2,000 volts. The field-coil is wound on a circular copper spool resting in the centre of the machine and surrounding the inductor. Particulars of the efficiency of machines of different sizes at various loads are given. They regulate from 6 per cent. to 9 per cent., according to their size. The machines are said to give a sine curve, and will run well in parallel.

The conditions necessary to be fulfilled by a motor are thus enumerated: (i) it must start from rest in any position with a torque much greater than that exerted when running; (ii) its speed must be approximately constant under great variations of load; and (iii) it must not disturb the pressure of the circuit. The motor which forms part of the system described has two fields fed by currents differing 90° in phase, and two armatures mechanically coupled, and so connected electrically that a wire directly under the poles in one is between the poles in the other. One-half the machine is thus a motor, the other a transformer. The fields are fed at 500 volts. Short-circuited coils of high conductivity are placed in the field-poles, their effect being, it is stated, to increase the starting torque from 50 per cent. to 200 per cent. above full-load torque. A condenser is connected in parallel with the field-magnets, and supplies the "false" current. The efficiency of the motors is said to be 90 per cent. in the larger sizes, 80 per cent. for 5 HP., and 70 per cent. for 1 HP., measured in all cases by a wattmeter. The variation in speed between full-load and running light varies from 6 per cent. to 10 per cent. according to the size. These motors have been in successful use on two-phase circuits at Pittsfield for over a year and a half.

C. H. W.

The Manufacture of Chloride Accumulators.

(The Electrical Engineer, New York, 1895, p. 491.)

Reference having been made to the importance of the storage battery at the present time, and the bearing its use has on the size of the units to be adopted in central stations, the method of manufacturing the chloride cells by the Electric Storage Battery Company of Philadelphia is described.

It is essential that the active material should be homogeneous, and the company has found after much experimenting that chloride of lead is the most suitable compound from which to prepare the spongy lead, and in order to ensure purity the chloride of lead is prepared at the works. Commercial lead is finely divided by causing a blast of compressed air to act on a fine stream of molten lead, and the powder so formed is dissolved in

nitric acid and the lead precipitated as chloride of lead by the addition of hydrochloric acid. The precipitate is then thoroughly washed and dried, every care being taken to prevent the introduction of impurities.

The chloride of lead is then mixed with some chloride of zinc, and the two melted together and cast into pastilles, each of these having a hole in its centre. These pastilles are then placed in a mould, being held in position by pins passing through the holes, and molten lead, alloyed with a small amount of antimony to render it stiff, and less liable to corrosion, is forced into the mould by an air-pressure varying from 75 lbs. per square inch to 180 lbs. per square inch, according to the size of plate being made; the process is very rapid, and blow-holes are entirely avoided.

The plates, after being scraped and finished, are stacked up with a plate of zinc between each one and the next in a tank containing dilute chloride of zinc. The primary battery so formed is short-circuited, with the result that the pastilles give off the chlorine to form chloride of zinc, and crystalline lead is left behind.

This process takes about forty-eight hours, and on its completion the plates are thoroughly washed in running water. A connecting lug of lead is then burnt on to each plate by the hydrogen flame, and those intended for negative plates are now ready for use; those that are to be used as positives are formed by being placed in tanks containing dilute sulphuric acid and by being charged continuously for two weeks in one direction; the spongy lead is thus converted into peroxide of lead. The floor of the room in which this process is carried on is of asphalt, and the ceiling of hollow tiles supported by steel columns covered with acid-proof paint. Current is supplied at 125 volts by one 500-ampere and two 200-ampere machines, and is carefully measured by means of Weston instruments.

When the plates are made up into cells, great care is taken to keep those of opposite polarity apart; for this purpose, each positive plate is covered on both sides with asbestos cloth, and partitions of cherry wood, perforated with numerous holes connected by grooves, are placed between the plates. The wooden partitions are perforated by a machine which drills sixteen holes simultaneously in twelve boards, and the grooves cut by means of eight circular saws mounted together. A revolving circular knife is used for cutting up the asbestos.

The cells are made in all sizes from 1,000 ampere-hour cells to cells only 2 inches by 4 inches, containing three plates, and intended for long-distance telephone work.

The article is fully illustrated.

C. H. W.

A new Meter for Alternating Currents. By Wm. S. Resor.

(The Electrical World, 1894, p. 268. 6 Figs.)

The Author states that one of the problems which has confronted electrical engineers has been the invention of a commercial alternating-current recording meter which will record all loads correctly. He believes that this problem has been solved by Mr. Thomas Duncan of the Fort Wayne Electric Corporation, Fort Wayne, Ind., U.S.A. After remarks about unsatisfactory meters, he explains that this meter is dependent upon the principle of the repulsion of a closed secondary from its primary, and is a development of Professor Elihu Thomson's classical experiments on that principle.

The essential parts of the meter are the primary or field-coils, which are connected in series with the lamp-circuit; the secondary or armature, consisting of an aluminium cylinder, a magnetic path-diverter, made of laminated iron and carrying a closed secondary which consists of several copper punchings; the aluminium fans, the registering train, and the spindle which carries the said armature and fans. There are no brushes or commutator to get out of order, or other contacts to become dirty and oxidized. The armature has no electrical connection with the circuit. The motion of the armature or cylinder is due to the repulsion set up against it as a closed secondary from the primary or field-coils. When the lamps are turned on, the current flows through the primary coils and an alternating field is set up. This field is distorted or diverted from its natural direction by a part called the diverter, and assumes a form shown diagrammatically in the original. Foucault currents are generated in the armature, and also in the closed secondary on the diverter. The use of this secondary on the diverter is to reverse its polarity.

The rotation is due to the repulsion set up by the two similar poles on the outside of the cylinder and the attraction between the two unlike poles inside. The closed secondary, which is divided into two parts, each half being placed upon the respective poles of the diverter, is for the purpose of changing the original or induced polarity of the diverter, so as to obtain a maximum torque in effecting an attraction between the induced poles, on the inner surface of the cylinder and the diverter.

The Author states that this meter is the only one the speed curve of which is a straight line.

A Table of the results of tests on a twelve-light Duncan meter is then given, from which it appears that when only one lamp is connected there is an error of 6·6 per cent., but when two lamps or any number up to fifteen lamps are connected there is no error. The initial speed is constant at 15 revolutions, while the revolutions per minute vary from 14 with one lamp to 225 with fifteen lamps.

Similar tests on a twenty-five light meter show an error of 10 per

cent. when only one lamp is connected, and afterwards no error up to full capacity. The error on a fifty-light meter with one lamp only connected was 15 per cent., and afterwards no error. It appears that Mr. Duncan has applied the same principle to meters for measuring and recording multiphase currents, and with particular success in the case of two- and three-phase currents. A peculiarity of the multiphase current-meter is that it can be used for single-phase currents by connecting its field-coils in series or parallel, and in series with the lamps.

E. R. D.

The new Telephone System of Paris. By E. Hospitalier.

(La Nature, 1895, p. 38 *et seq.*)

Having referred to the extreme rapidity of the growth of telephony and the difficulty of keeping pace with requirements arising from an increased number of subscribers, the Author proceeds to trace the development of telephony in Paris up to 1889, in September of which year the telephones were taken over by the State, there being at the end of the year 6,255 subscribers. This number increased to 8,306 in 1890, 9,653 in 1891, and had risen to about 14,000 at the beginning of 1895. The Author points out that since the expenses for installation, maintenance and attendance increase approximately as the square of the number of subscribers, a time must arrive when the service will cease to pay at the present price; moreover, if the subscribers reached 150,000 to 200,000, the telephone would become useless on account of this excessive number and the consequent slowness of communication.

At the time of the transfer, the 6,000 subscribers were divided among twelve exchanges; this large number of centres had the advantage of reducing the mean length of the lines, but involved the serious drawback that nearly all conversations had to take place through two exchanges. In the present network there are only four exchanges, two having 6,000 subscribers each, one 3,000, and the fourth being still in course of construction; when complete, the total number that can be dealt with will be 20,000. This figure will probably be reached in the near future when the whole system will have to be reorganised, it being already, although not yet complete, behind the most modern practice.

A metallic return is used for all circuits, and all wires are underground. The two subscribers' lines are insulated with gutta-percha and form a twin-wire, lead covered. This runs in a culvert parallel with the lines of other subscribers up to a "junction-box" where seven such twin-wires are connected to a fourteen-wire paper-insulated cable. Seven of these cables are joined in a "disconnecting-box" to a 104-wire cable, also insulated with

paper, running into the exchange building. The six spare wires of the large cable are reserved for use in the event of any of the other wires becoming faulty. The twin wires are fairly short; the mean length of the fourteen-wire cables is 1¼ mile in Paris itself, but is as much as 3¾ miles for the outlying subscribers; while that of the 104-wire cables is 1 mile, with a maximum of 2½ miles.

The process of manufacture of the 104-wire paper-insulated cables is described and the reasons given for their being substituted for those formerly used which were insulated with gutta-percha. Particulars are given of their electrical and mechanical properties, and reference is made to the method of forcing dry air into them which is in use.[1]

From 120 to 130 of the large cables enter an exchange for 6,000 subscribers, and they are carried in a trough which is made of sheet-iron to protect them from rats. Each cable ends in a cast-iron junction-box, which contains a sheet of insulating material carrying terminals to which the separate wires are brought. The terminals traverse the insulating base, and from their other ends are led off the wires of two 52-wire cables, two wires in each being kept in reserve. These cables go to a "distributor," the office of which is to enable any wire from outside to be connected to any number on the boards in the exchange; by means of this a subscriber is enabled to retain his old number in the event of his moving to a different locality (provided he is still connected to the same exchange), and confusion is avoided in the exchange if spare wires have to be substituted for a faulty pair in a cable. The cables coming from the junction-boxes enter at the top and back of the distributor, and the wires are attached to terminals fixed in vertical rows at the back. The cables from the switchboards contain forty-two wires, two being a reserve, and enter at the front, the wires being affixed to terminals on horizontal ledges. Twin-wires are used for joining the respective terminals together in the vertical and horizontal rows; an orderly appearance is preserved by carrying the wires from front to back on horizontal frames or racks, instead of taking them direct to their several destinations.

The Author passes on to describe the exchange, selecting that in the Rue Gutenberg, having capacity for 6,000 subscribers, as an example. The multiple system is adopted, each line terminating in a flexible cord and plug. Three operators attend to each board, to which are brought 240 subscribers, and there are twenty-three boards, half boards being placed at the two ends to facilitate the work of the end operators. Each panel is 6 feet 7 inches wide and 5 feet 3 inches high. A general description of the method of connecting two subscribers and of the method of testing whether lines are engaged or not is given.

The operators' transmitters are of the Hunnings type, and are

[1] Minutes of Proceedings Inst. C.E., vol. cxix. p. 501.

suspended from flexible cords in such a way that their height can be adjusted. The receivers are supported by a light band of steel passing over the head, and weigh only 5¼ ozs.; they are provided with an additional winding for use when testing if a line is engaged.

The lines connecting the exchange with the three others are divided in each case into two parts, half being "departure" lines, or lines on which the operators call other exchanges, the other half being "arrival" lines, or lines on which other exchanges call them.

A separate exchange is provided on the first floor for suburban and inter-urban communications; the lines pass through it before entering the main exchange, and a special board is fixed which enables the main boards to be cut out, thus avoiding the introduction of the capacity of the exchange cables into the circuit. The action of cutting out the jacks of a line on the main boards puts them to earth through a battery, thus causing them to give the usual sound of an engaged line in the operator's telephone.

The building in which the Rue Gutenberg exchange is situated covers an area of 15,070 square feet and is airy and well lighted. The cables enter in the cellars and the distribution of the lines is there effected; the ground floor is used for postal vans; the first is assigned to the inter-urban switchboards, the second to the main exchange, while the third and fourth are reserved for extensions.

C. H. W.

On the Degree of Incandescence of Lamps. By A. Crova.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxix., 1894, p. 627.)

The determinations were effected with the spectrophotometer. Comparison was first made with a standard lamp, a tank containing a solution of nickel chloride and ferric chloride being interposed between the eye and the photometer. The metallic salts were mixed in such proportions as to transmit rays of the wave-lengths comprised between 630 and 534, with a well-defined maximum at 582. From this measurement the illuminating power in carcels was determined.

The tank was then removed and a red glass, transmitting the less refrangible rays nearly up the D line, was substituted for it. The relation between these two measurements is termed the degree of incandescence.[1]

The Author gives some examples of the application of this method to the electric glow-lamp and the arc light. He also quotes experiments with various kinds of gas burners.

---

[1] Comptes Rendus, vol. xciii. p. 512.

With a Bengel burner the following results were obtained:—

Illuminating Power.	Consumption of Gas	
	Per Hour.	Per Carcel-hour.
Carcel.	Litres.	Litres.
0·2	56	280
0·4	78	195
0·6	95	158
0·8	108	135
1·0	120	120
1·2	121	109

With more than 131 litres per hour the flame became smoky. But the degree of incandescence diminishes slightly before the maximum of illuminating power is reached.

Different results were obtained with the Auer incandescent burner.

Illuminating power	carcels	4·42	5·23	5·35
Degree of incandescence		1·30	1·41	1·47
Consumption of gas per hour	litres	93	105	102
Consumption of gas per carcel	,,	21	20	19

With incandescent burners it is therefore advantageous to push the degree of incandescence to the point beyond which no further increase in the consumption of gas is capable of affecting it.

G. J. B.

Electric-Light Stations in France, to January 1st, 1895.

(L'Industrie Électrique, 1895, p. 32.)

The editor gives a supplement describing in tabular form all the provincial electric-light stations organized in France up to January 1st, 1895. Information is given as to the date when the supply was commenced, the prime movers employed and their HP., the make of dynamo used, the system of main, and the charges for light, &c.

The Author summarises the results as follows:—

There are 328 supply-stations in France now at work, not counting those in Paris. These can supply a total of about 40,000 HP. by prime movers of different types as follows:—

——	Number of Station.	HP.	Percentage of Total HP.
Water-power	151	9,650	24·5
Water-power and steam	39	6,000	15·0
Steam alone	119	22,000	56·0
Power gas	5	220	0·55
Town gas	14	1,550	3·95

The systems of continuous, alternating, and polyphasis current have the following support:—

——	Number of Stations.	HP.	Percentage of Total HP.
Continuous	260	27,895	70·7
Alternating	73	10,645	27·0
Polyphasis	5	880	2·25

There have been during 1895 twenty-seven new stations started and thirty-four are at present in course of construction.

R. W. W.

Electric Lighting by Water-power at Peterborough, N.H., U.S.

(The Electrical Engineer, New York, 1895, p. 245.)

Having referred to the great difficulty of making a central station pay in a town of 5,000 inhabitants or less, more especially when fuel is dear, as it is in the interior of New England, the Author describes a plant which has been in operation for a year in Peterborough, N.H., and attributes its success to improvements in alternating-current apparatus having rendered the use of distant water-power practicable.

The business quarter consists chiefly of one street about 170 yards long, and from this the residential streets radiate for considerable distances up the surrounding hills. The town is a manufacturing one, and the population is slightly, if at all, in excess of 2,500. There is a public library, an opera-house, an hotel, and a few mansions, but the majority of the houses are seven- or eight-roomed cottages.

The station is 3½ miles from the centre of the village, near a stream fed from half a dozen ponds. A subsidiary reservoir is formed by a dam, and the storage is ample for the driest season. A Rodney-Hunt turbine, working under a head of 24 feet, and provided with an automatic regulator, drives a shaft at 232 revolutions per minute through the intervention of bevel-wheels. On this is keyed an 84-inch pulley, driving a Thomson-Houston dynamo at 1,500 revolutions per minute, which gives 60 kilowatts at a pressure of 2,080 volts. This shaft also drives a saw-mill during the day, and is provided with a fly-wheel weighing 1,200 lbs. in order to steady it. The switchboard is fitted with an ammeter and voltmeter for the line, an ammeter for the exciter, an earth-detector, a five-light transformer, and rheostats for the field-magnets.

The line goes from the station to the town and branches are taken into all the principal streets. It is of No. 3 Okonite wire, and is carried on glass insulators fixed on cedar poles 25 feet

high, about 125 feet apart. The drop is calculated at 10 per cent. A telegraph and a telephone line are run on the same poles.

Distribution is effected at 104 volts by means of transformers placed in pairs on the poles and feeding separate three-wire secondary systems. There are six such centres at present in the main village, and one at a village midway between it and the station, every consumer being within 500 feet of a distributing pole. The secondary mains are carried on the same poles as the primary, and vary in size from No. 8 wire for the outers, with a No. 10 for the middle, to No. 3 for the outers, with No. 6 for the middle. The loss in the transformers and distributors does not exceed 6 per cent., and the whole variation in pressure throughout the system is said to be less than 2 per cent. Lightning arresters are placed at the ends of the branches of the primary, on the switchboard, and two on each transformer. Thus far they have afforded protection.

There are eighty-one street lamps of 25 candle-power. They are fixed about 15 feet from the ground on curved iron brackets projecting from the poles which support the wires. In the main streets there is a lamp on each pole, in the less important on alternate poles. The streets are 60 feet wide, and the illumination is said to be satisfactory.

The total number of lamps connected is about 1,000, including the street lamps, and the average current from the station is 13 or 14 amperes, occasionally reaching 17 amperes. All current is sold by contract, consumers renewing their own lamps.

The plant is superintended and run by one man without skilled assistance.

The Author, being unable to give the actual figures relating to the cost of the enterprise, concludes with an estimate of the expenditure for a similar plant for capital and working expenses, and of the receipts.

C. H. W.

The Lighting of Railway Carriages by means of Electricity.

By A. De Pontcarré.

(L'Électricien, 1894, p. 296.)

The Author describes the system of lighting fitted by the Allgemeine Elektricitats Gesellschafts in the express trains running from Paris to Lille. Mr. A. Sartiaux, the manager of the railway company, laid down the following conditions to the contractors:—

1st. The candle-power of the lamps to be 10, 8, and 6 candle-power in the 1st, 2nd, and 3rd class compartments respectively.

2nd. Each carriage to carry its own source of lighting, *i.e.*, accumulators

3rd. In case of breakdown, facility to be supplied for quickly lighting by oil without interfering with the electric fitting.

4th. The accumulators to be arranged so that they can be charged *in situ* or easily withdrawn to be charged.

In this case sixteen accumulators were used in each carriage, weighing in case 860 lbs. These were found to be able to supply light for thirty-five hours without recharging.

The total cost of fitting up a carriage of four first-class compartments was £29 including accumulators. The cost of upkeep per lamp-hour (of 10 candle-power) was found to be as follows:—

		d.
Electricity at 1·9*d.* per B.T.U.	=	0·080
Upkeep and renewal of batteries at 10 per cent. of prime cost	=	0·051
Renewal of lamps	=	0·062
		0·193

In the capital account the Author charges 4 per cent. for interest, but allows no depreciation on the accumulators beyond the 10 per cent. already allowed, and only 5 per cent. depreciation on the rest of the plant. This makes the capital charge 0·046*d.* per lamp-hour, and the total charge then is 0·240*d.* per lamp-hour of 10 candle-power.

The Author states that for oil-lamps with circular burners of 7 candle-power the total charges come to 0·365*d.* per lamp-hour. These charges do not include labour in handling the accumulators, which may be of the same order as the labour expended in trimming oil-lamps. In this case the actual expenditure under this heading was 0·031*d.* per lamp-hour.

The article is illustrated by two blocks, and the figures of costs are obtained from the chief electrician of the Northern of France Railway Company. R. W. W.

The Central Stations for the supply of Electric Energy in Paris.

By J. Laffargue.

(L'Industrie Électrique, 1894, p. 466.)

The Author has collected details of the generating plant now installed by the various electric supply companies in Paris and tabulates these particulars under the following headings: boilers, engines, dynamos, system of distribution, feeders and mains, transformers, accumulators and total power available. He also reviews the progress made during the last two years by each individual company as shown by reference to similar details published by him in the above journal, vol. i, p. 441. The most

marked improvements have been made in the mains and feeders, which in the past have given trouble.

The Author deals with the generating and distributing plants only, and gives no particulars of the annual output of the stations. The Tables give interesting information as to the extent to which the various systems of distribution are used in Paris as evidenced by the power of the machinery employed.

System.	HP. of Dynamos.	HP. of Accumulators.
Two-wire low tension with feeders	3,500	500
Three-wire „ „ „	3,550	275
Five-wire „ „ compensators placed in regulating stations	2,750	540
High-tension continuous current at 2,500 volts with continuous current transformers	800	..
High-tension continuous current used to charge batteries in sub-stations in series, also some continuous-current transformers	2,810	270
Alternating-current high tension with transformers in consumer's premises	2,080	..
Total	15,490	1,585

Information under the heading "feeders and mains" shows that seven of the stations use bare copper conductors laid in culverts, five use lead-covered iron-armoured cables laid direct in the ground, five use insulated cables protected by paraffined wood in culverts, and the remaining three stations each use some different system.

The article is accompanied by a map of the districts lighted by the various companies.

R. W. W.

Electric Carriages. By J. Reyval.

(L'Éclairage Électrique, 1894, p. 454 *et seq.*)

The Author reviews first the other systems of self-propelling carriages, and then the past history of electric carriages. He proceeds to describe six electric carriages by different designers.

He points out the great advantage primary batteries have over accumulators in point of weight and ease in recharging; but, unfortunately, the cost of upkeep of primary batteries is greater than for accumulators.

The list below is abstracted from the Author's descriptions of the various electric carriages:—

Name of Designer.	Country.	Accumulators. Type.	Number.	Weight Complete.	Capacity.	Weight of Carriage Complete in Lbs.	Speed in Miles per Hour.	Motors.	Gear.	Remarks.
				Lbs.	Watt-Hours.					
Pouchain .	France .	Dugardin	..	..	..	3,000	8¾	2 HP. available from battery	..	Three-wheeled carriage to hold four persons.
Cummings	America	..	..	..	..	..	10 to 12	2 HP. 25 volts	Double reduction	Four wheels — will hold four persons.
Carli . .	Italy .	Verdier.	10	120	2,000	..	..	Speed 1,000 to 2,000 revolutions per minute.	Gear reduction 1,000 to 30	A system of rubber springs wound up by hand assist at the start.
Blanche .	France .	Regnier (zinc)	32	440	5,000	..	..	Siemens D 5 70 volts. 1 B.HP. obtained at wheels	..	Usual current 8 to 15 amperes.
Garrard and Blumfield	English origin .	..	24	500	..	1,100	7½ to 11	..	See footnote [1]	Steel tubular frame with pneumatic tyres on wheels—four wheels.
Farigay .	France .	Primary battery, Bunsen	36	280	3,600	880	..	..	Chain gear [2]	Three-wheeled vehicle for two persons. Steel tubular frame, pneumatic tyres.

[1] The gear used in the Garrard-Blumfield carriage permits of the motor running always. The motor drives a disk, geared to the car-wheels, by means of a friction-roller. The friction-roller can be adjusted along a radius of the disk it drives, and the speed of the carriage is adjusted in this way.

[2] There is besides an arrangement for connecting up the batteries in groups parallel to increase the driving torque at low speeds.

R. W. W.

Operation of Induction-Motors on the General Electric Company's Monocyclic System.

(The Electrical Engineer, New York, 1895, p. 256.)

Although a few synchronous single-phase motors have been used they are not suitable for general use, and two- or three-phase currents are not available on ordinary circuits, so that motors of that class cannot be used; the monocyclic system was devised in order that one generator might supply both power and light.

The action of an induction-motor when run on this system is stated to be as follows: When one field-coil is excited by a single-phase current, a secondary current, lagging 90 degrees behind it, is induced in the closed armature coils. If, now, by some external cause, a field at right angles to the first is set up and displaced in phase, maximum torque on the armature is produced. When the motor is running, the current in the armature supplies the displaced field, and actually induces an electromotive-force in the coil which originally supplied it sufficient to give the required current in a similar coil on another motor running from the same mains if the coils be connected together.

A supplementary wire is therefore supplied connecting all the field displacing coils together, and, so long as one motor on the circuit is running, any of the others can start at maximum torque. Since only a magnetizing current is conveyed, the cross-section of the wire need not be great. To meet the case presented when no motor is running, the equalising wire is run back to the generator which, by means of a small supplementary coil, furnishes the current necessary to cause the first motor to start. It is evident that for lighting only the ordinary two wires are required. The periodicity is 60 for ordinary work and 33 for very long distance transmission.

The field-magnets and armature of the motor are of laminated iron well annealed, and the latter is wound with heavy copper bars connected at the ends. A starting resistance is provided and is wound within the armature-spider; it is cut in and out by means of a switch worked by a collar sliding on the shaft. The resistance is usually arranged to give a torque at starting 50 per cent. greater than that at full load, but in special cases the starting torque is made three or four times as great as the running torque.

C. H. W.

On the Transmission of Power by Electricity.

By G. DUMONT, G. BAIGNÈRES and A. LENCAUCHEZ.

(Mémoires et Compte rendu de la Société des Ingénieurs-civils, December, 1894, p. 760.)

This Paper occupies 116 pages of the publication named above, and is a general treatise on the subject dealt with, not affecting to offer any novel views on the subject or to deal with topics of controversy. It is divided into four parts:—

(1) The transmission of energy to long distances.
(2) Transmission to short distances and distribution in factories.
(3) Instances of such transmissions.
(4) Prime movers for generating electric currents.

Under the first head the superior economy of electric transmission over other methods is insisted on, and the necessity of employing high tension is demonstrated. The limit of tension within which continuous currents can be successfully used is given as from 2,000 to 3,000 volts; when the length of line is so great as to require, for economy, a higher tension than this to be employed, it becomes necessary to resort to alternate currents, with which there is no difficulty in transmitting at a tension of 10,000 volts. The production of currents at these high tensions being attended with certain dangers, a common practice is to generate an alternate current at moderate tension, transform it to high tension for transmission, and transform back again to lower tension for distribution at the receiving station. The commercial efficiency of the alternating generator is given as 80 per cent. to 85 per cent., that of the alternating motor as 70 per cent. to 80 per cent., that of each transformer, at full load, as 95 per cent., and that of the line, with overhead wires, as 85 per cent. to 95 per cent., according to distance. This gives, as the total efficiency of the electrical apparatus (with two transformations), from 61 per cent. to 73 per cent. when the current is used for lighting, and from 43 per cent. to 58 per cent. when it is used for motive power. These figures are supported by three examples from Italy and from California, where the distances are 15½ miles, 15 miles, and 28 miles. There are difficulties, however, in the generation and utilization of alternate currents for motive-power purposes, and these have led to the invention of the revolving magnetic field by which these difficulties are avoided. The theory of machines of this class (multiphase machines) is explained, and two instances of triphase transmission are given.

Under the second head, the Authors express the opinion, that the use of electric currents for the distribution of power to the different machines of a factory will very largely increase when owners and managers have learnt to understand the advantages of the system. These advantages comprise,—a greater efficiency; economy realised by concentrating the production of motive power at one point; greater facility for placing the machines in the most

convenient sites, and for changing the position of them, or adding to their number when desirable; improved power of regulating the speed of machines, and of starting and stopping them, &c. Continuous-current machines only are dealt with in this chapter, and the following points are discussed, viz.:—the general theory of the action of an electric motor; the calculation of the current developed; various methods of exciting the field magnets; regulation of speed, calculations of efficiency, and its variation with load and speed; various methods of placing the motors in circuit, and the methods to be adopted for calculating a distribution of power for any given case, illustrated by an example worked out. The question is next discussed as to the choice to be made between giving a separate motor to each machine, and arranging the machines in small groups, each machine of one group being driven from a common shaft, actuated by one electromotor for the group. This choice depends partly on the work absorbed by shafting and belting, as to which experiments are quoted. A Table is also given of the losses in transmission of power by mechanical means in a great variety of workshops, according to results collected and published last year by a congress of the Steam-engine-Owners Association of France.

In the third section a description is given of electric transmission of power for actuating lifts, fixed and moveable cranes, pumps, machine-tools, stone-saws in a quarry and other purposes at various establishments in France, Belgium, and Algiers. The commercial efficiency of these installations—*i.e.*, the ratio of the power available on the shaft of the electric motors to the indicated power of the steam-engine or other prime mover—ranges from 63 per cent. to 69 per cent.

The fourth section discusses the conditions necessary for the best efficiency of steam-engines and boilers, and also describes the gas-producers by which cheap gas suitable for gas-engines may be made.

C. F. F.

The Electric System of the Philadelphia Traction Company.

By H. S. Hering.

(The Electrical World, New York, 1894, p. 383. 11 Figs.)

The Author states that the Philadelphia Traction Company was the first of the street railway companies in Philadelphia to change its motive power from horses to electricity. The use of the trolley system was very much objected to in Philadelphia, but as the company bound themselves to repave the streets at their own expense with asphalt, to run the feeders underground, and to use iron poles, the requisite permission was granted by the municipal authorities. The first portion of line to be equipped was that passing through Catherine and Bainbridge Streets. Within the

last two years, and chiefly within the last six months, between 100 miles and 200 miles of trolley-roads have been laid and worked in Philadelphia or are about to be started. At present, the company is working about 119 miles of equivalent single track electrically, 34 miles by means of cables, and 25 miles by horses, making a total of 178 miles. Extensions are contemplated which will bring up the mileage to 300.

The complete cost per mile, not including power-stations, has been about £6,250, and the company has already spent nearly £1,000,000.

A map in the original shows 190 miles of single track.

The power is generated in four stations. Station A at Sutherland Avenue and Kansas Streets feeds the southern portion of the city, and was the first one built; Station B at 13th and Mount Vernon Streets, feeds the central portion; Station C at 33rd and Market Streets, feeds West Philadelphia; and Station D at 32nd and Dauphin Streets, which is nearly complete and is to feed the lines in the northern part of the city. These stations aggregate at present 11,550 HP. and have an ultimate capacity of 19,800 HP.

Station A was built for the first portion of the line opened. The dimensions of the original building were as follows:—Engine-house 72 feet by 66 feet, and boiler-house 72 feet by 64 feet, both being about 36 feet high; those of the addition are engine-house 115 feet by 53 feet 6 inches, boiler-house 130 feet by 45 feet, and both are about 35 feet high. The boiler equipment originally consisted of six 150 HP. Wetherill steam tubular boilers 20 feet long by 6 feet diameter, and there has been an addition of ten 125-HP. boilers of the same kind, 20 feet long by 5 feet diameter. Natural draught is used, the original chimney, which is of sheet iron with a brick base and made by the Convery Boiler Company of Philadelphia, is 6 feet 6 inches diameter and 135 feet high. The steam mains are arranged so that any boiler can be connected to any engine, the pipes are 12 inches diameter, and the steam-pressure used is 125 lbs. per square inch. The original engine-equipment consists of three single-cylinder Wetherill engines each developing 250 HP.; the diameter of the cylinder is 22 inches and the stroke 48 inches. These engines run at a speed of 75 revolutions per minute, and each is connected by belting to a 250-HP. Westinghouse four-pole high-speed generator running at 525 revolutions per minute.

The engine driving-pulley is 18 feet diameter and 31 inches broad, and that of the generator is 31 inches diameter. A jockey pulley 36 inches diameter is used to press upon the belt and increase the contact.

The new equipment consists of two 750-HP. Wetherill-Corliss engines, cross compound condensing.

These engines are directly coupled to a 750-HP. Westinghouse multipolar generator of the new type and are used non-condensing, but are arranged to be used condensing if desired. There will be either another 750-HP. or else a 500-HP. machine put in during

the coming year. The following Table gives the capacity of the power stations:—

Station.	Floor Space.		Boilers.		
	Boiler-Room.	Engine-Room.	Make.	Present HP.	Ultimate HP.
	Square Feet.	Square Feet.			
A	10,458	10,904	Wetherill	2,150	2,150
B	13,700	14,280	Babcock and Wilcox double deck . . .	3,750	7,500
C	11,637	11,784	Ditto	3,000	6,000
D	7,029	7,029	Wetherill "Berry" .	..	2,000
	42,824	43,997	.. ..	..	..

Station.	Engines.			Generators.			Cars worked at Present.
	Make.	Present HP.	Ultimate HP.	Make.	Present HP.	Ultimate HP.	
A	Wetherill .	2,250	2,250	Westinghouse	2,250	2,250	52
B	Westinghouse	3,000	3,000	,,	6,000	9,000	270
	Wetherill .	3,000	6,000				
		6,000	9,000				
C	Westinghouse	1,800	1,800	,,	3,300	6,300	70
	Wetherill .	1,500	4,500				
		3,300	6,300				
D	Wetherill .	..	2,250	,,	..	2,250	..
	..	11,550	19,800	..	11,550	19,800	392

Station D is not yet in operation.

Station B was the second built and is the largest of all. The front on Mount Vernon Street is 100 feet long, and built in three floors 21 feet wide, in which are the offices of the staff, drawing-office and testing-room. Behind the block and extending along 13th Street is the engine- and dynamo-room, which is 146 feet 5 inches long, 97 feet 6 inches wide, and 60 feet high. The boiler-house is 169 feet 6 inches by 80 feet 10 inches, and about 60 feet high: it contains at present ten 375-HP. Babcock and Wilcox double-deck boilers, and has room for ten more, of which five are now being installed.

Induced draught is produced by four Sturtevant blowers, one for each battery of five boilers. There are two iron chimneys, one for each side of the boiler-house; each is 10 feet 6 inches diameter, and the top is 27 feet above the blowers and 70 feet above the grates.

There are two ash tunnels 7 feet wide and 7 feet 8 inches high running the entire length of the building, and under each boiler is an ash hopper through which the ashes are discharged into the tunnel.

The Author then gives details as to the water-supply and feed-pumps.

To prevent scale in the boilers oil is added to the feed-water. Kerosene with a flash point of 150° is used, and about 6 gallons are fed in about twenty-four hours for 2,000 HP.; this method is being tried as an experiment and so far has answered well. The coal is carried to the top of the building by a special system of conveyers worked by two 35-HP. Westinghouse engines.

About 60 tons of anthracite pea-coal is used daily.

The equipment of the engine-house consists at present of five Westinghouse vertical compound engines, each coupled to a Westinghouse generator of the four-pole type. Each engine is rated at 600 HP. with 140 lbs. steam pressure and at a speed of 215 revolutions. The cylinders are 23 inches and 40 inches diameter, and the stroke is 20 inches. The rest of the equipment will eventually consist of four 1,500-HP. engines, but at present only two are installed; these are of the Wetherill-Corliss type, with cylinders 26 inches and 40 inches diameter and stroke of 48 inches. The fly-wheel is 21 feet in diameter and its rim weighs 100,000 lbs.

The generator has ten poles placed radially on a circular yoke 12 feet 6 inches outside diameter. The armature is 90 inches and the commutator 60 inches diameter.

The switchboard is 96 feet long and controls about 100 feeders, although its ultimate capacity is 250. A detailed description of this large board is given.

The Author then describes the rest of the stations, but these do not appear to present any great variety on those of which an abstracted account has already been given above.

E. R. D.

Electric Traction in Mines. By J. Libert.

(Annales des Travaux publics de Belgique, 1894, p. 131.)

Up to the present time the only application of electricity for traction in the Belgian collieries is to be found in two electric locomotives at the Amercœur collieries at Jument in the Charleroi coalfield. Secondary batteries of the Julien type carried by the locomotives supply the current. The line is in an underground gallery 1,720 yards long laid with rails weighing 24 lbs. per yard on a half-metre gauge. The minimum curves have a minimum radius of 26 feet, and the average gradient is 1 in 370 in favour of the load. By a number of experiments it was determined that resistance to traction might be taken between ½ and 1 per cent. of the load. The first locomotive was put to work in July, 1893, and the second, which is slightly heavier was built soon after-

wards. Chain driving-gear is used on the first with a single motor, whilst the second carries two motors driving through spur-gearing. Particulars of the two engines are given below:—

Length over all	feet	12·58	14·96	
Breadth	„	3·94	3·28	
Height	„	3·57	4·35	
Number of axles		2	4	(two bogies)
Weight of truck	lbs.	2,535	4,740	
„ batteries	„	3,174	3,417	
„ motors	„	1,234	1,763	
Total weight	„	7,054	9,920	
Current at motor	volts	70	70	
„ „	amperes	30	30	
Revolutions of armatures per minute		1,020	680	
„ countershaft „		204	340	
„ driving axles „		85	85	
Working speed per hour	miles	5	5	
Tubs hauled per journey	number	15	20	
Total load hauled per journey	tons	9·75	13	
Coal hauled per journey	„	6	8	
Tubs hauled per ten hours	number	300	400	
Coal „ „	tons	120	160	
Normal capacity of batteries	ampere hours	465	485	

Series wound tripolar motors of the Lahmeyer type with Siemens armatures are used. The brushes are of carbon electroplated with copper. A resistance switch controls the current for starting and stopping, and another switch changes the direction of the current through the armature to reverse the locomotive. Ample platform space is left for the driver on the engine, of which two folding plates show the construction. The cost per ton-mile with the two locomotives is calculated to be 1·2 and 1 penny, a result not differing greatly from that obtained at Marles in the Pas de Calais. The cost of horse-haulage cannot now be accurately ascertained, but it is estimated at 2·5 penny per ton-mile.

R. E. C.

Mine-Locomotives with Secondary Batteries. By F. Cambessèdes.

(Bulletin de la Société de l'Industrie Minérale, 1894, p. 607.)

At Amercœur, near Charleroi, in Belgium, electric traction has been applied in a gallery joining two pits 1,575 metres apart, in which, to avoid the cost of overhead conductors, the principle of driving by secondary batteries carried on the locomotive is adopted. The gauge of the line, which is laid with fish-jointed flange rails weighing 12 kilograms per metre, is 500 millimetres, the minimum radius of curvature is 8 metres, and the average gradient (in favour of the load) 1 in 370. The first locomotive, built in 1893, resembles a low-sided goods-wagon, having a rectangular body 2·725 metres long and 1·2 metre

broad, carried on two axles 1·1 metre apart, the length being further increased by a platform for driver and brakesman at either end to a total of 3·969 metres. The secondary batteries, on Julien's system, include 36 elements, each containing twelve 300- by 200-millimetre lead-plates, with an active weight of 31 out of a total of 40 kilograms. These are arranged in four groups of nine in covered ebonite boxes, two being placed at either end, leaving a space 525 millimetres long in the centre for the motor. The boxes are connected by naked copper-wire, and the main conductors to the motor are in tinned-copper, insulated with vulcanized rubber; their section is 28 square millimetres allowing the passage of a current of 100 amperes without being unduly heated. The total capacity of the battery is estimated at 465 ampere hours, or 15 ampere hours per kilogram of plate employed.

The motor is of the Lahmeyer type, with bipolar field-magnets of cast-iron, series-wound, and Siemens' drum-armature, the core being built up of alternating thin disks of charcoal-iron, and vegetable-parchment. The brushes of carbon, electro-coppered, maintain a fixed position on the commutator independent of the direction of rotation of the armature; and as the breadth of the pole-pieces is limited to about half the circumference of the latter, a neutral zone is obtained of sufficient breadth to prevent danger from sparking. The armature makes 1,020 revolutions per minute, which is reduced by two changes to eighty-five on the driving-axle, the latter receiving motion from an intermediate blind axle by means of pitch-chains. The wheels are 500 millimetres in diameter, giving a travelling speed about 2·4 metres per second, or 8 kilometres per hour.

The total weight of the locomotive is 3,200 kilograms, and that of the train drawn 9,750 kilograms, made up of fifteen trains of 250 kilograms, each carrying a load of 400 kilograms of coal, giving, with the engine, a total load of 12,950 kilograms. The journey of 1,575 metres is performed in eleven minutes, giving a useful effect of about 150 kilogram-metres (2 HP.).

The mean potential at the terminals of the motor being 70 volts and the current 30 amperes, the energy consumed is 2,100 watts, or 214 kilogram-metres, giving an efficiency of 70 per cent. According to the calculation of the Author, the disposable energy of the battery may be taken at 45·5 HP.-hour, to be expended during eight working hours in the shift, equal to 5·7 HP. gross exerted continuously, or 4 H.P. allowing 70 per cent. efficiency for the motor and transmission. This, however, is subject to some reduction, as it is necessary not to leave the batteries completely uncharged at the end of the day's work. What effect is realized from the batteries has not been determined, but experiments made with one of the same type under other circumstances showed, for twenty consecutive operations, charging and discharging, an average of 78·7 and maximum of 85 per cent. Allowing 80 per cent., and the same figure for the primary dynamo,

the mechanical effect realized becomes $80 \times 80 \times 70 = 45$ per cent. of that of the driving-engine at the surface. This is subject to a further deduction by the loss due to resistance in the cables connecting the dynamo with the charging-station, which does not appear to have been determined experimentally, but is computed by the Author to be equal to about 4·2 per cent., as the depth of the gallery below the surface is only 28 metres, and the length of conductor in the complete circuit not more than 150 metres. In a deep pit, say of 500 metres, requiring about 1,100 metres of cables, this loss would be very much larger, and might amount to 25 per cent. of the energy of the primary dynamo. In the present case we obtain as a final result that 40 per cent. of the power expended at the surface is reproduced in the driving-wheels of the locomotive, or about twice as much as can be obtained with compressed air, which rarely gives more than 20 per cent., except special means are adopted for supplying heat to the air during expansion.

The daily working cost of the locomotive is given as follows:—

	Francs.
Driver's wages	4·00
Motive power and charging cost, &c.	2·50
Maintenance of accumulators	5·00
Sinking fund and interest on capital	2·50
	14·00

This, upon the work done—300 tubs, with a net load of 120 tons, hauled 1,575 metres—corresponds to a cost of 7·4 centimes per kilometre (about 1·2*d.* per ton-mile), or rather less than half that of horse-traction, which is 16 centimes. In this estimate the duration of the positive plates of the accumulators is taken at a minimum of six months, but in actual work they have been found to be in perfectly good working order at the end of that time.

The locomotive described above has subsequently been supplemented by another of greater power, and differing in construction in several particulars, the most important of these being the substitution of two four-wheeled bogies for the two rigid axles of the first one, and the division of the power, each pair of axles having its own motor, with transmission by epicycloidal spur-gearing instead of a combination of spur- and chain-gearing driven by a motor common to both. The other differences will be seen in the comparative Table of dimensions given on the following page.

The second locomotive does not appear to cost more to work than the first; but assuming it to be 16 francs instead of 14 francs, the cost of the haulage, having regard to its capacity for taking heavier loads—160 tons instead of 120 tons—is notably reduced, namely, to 6·3 centimes per ton kilometre.

Figures of the two locomotives are given in the Plates illustrating the Paper.

——	Locomotive No. 1.	Locomotive No. 2.
Length over all	3·82 metres	4·56 metres
Breadth (extreme)	1·20 „	1·00 „
Height	1·15 „	1·325 „
Number of axles	2	4 (2 bogies)
Wheel base	1·10 metre	0·80 metre
Class of gearing	spur-wheel and chain	spur wheel
Weight of body	1,150 kilograms	2,150 kilograms
„ accumulator battery	1,440 „	1,550 „
„ motor	560 „	$2 \times 400 = 800$ kilograms
Mean potential	70 volts	70 (35×2) volts
„ current	30 amperes	40 amperes
Revolutions of armature	1,020 per minute	680 per minute
„ intermediate shaft	204 „	340 „
„ wheels	85 „	85 „
Normal speed per hour	8 kilometres	8 kilometres
Vehicles hauled per hour (maximum)	15	20
„ hauled 3·150 kilometres in ten hours (minimum)	300	400
Weight of electrodes per element	31 kilograms	33 kilograms
„ each element	40 „	43 „
Number of elements	36	36
Normal capacity of accumulators	465 ampere-hours	485 ampere-hours

H. B.

The Montreal Tramway System.

(The Electrical Engineer, New York, 1895, p. 520.)

The system is of recent construction and is further interesting on account of the frequent and heavy gradients, there being only two routes out of ten which have no gradients exceeding 1 in 20, and on some they are as heavy as 1 in 10, and also on account of the difficulty introduced by the snow which lies on the ground all the winter and reaches a depth of from 1 to 3 feet.

The importance of rapid transit is very great, as the city extends for 8 miles along the St. Lawrence River with an average width of 1½ mile. The system is worked by the Montreal Street Railway Company, under a concession from the city council, and particulars are given of the financial conditions of the agreement.

The generating station is situated about 1 mile from the centre of the lines. The boiler-room is 107 feet by 114 feet, and contains twelve double-flue Lancashire boilers, divided into two batteries, and generating steam at a pressure of 125 lbs. per square inch. The waste gases pass through a Green economiser, a by-pass being provided to turn them, if necessary, direct into the chimney; this last is 190 feet high, and has an air-space reaching within

30 feet of the top, the inner diameter of the core being 9 feet. The draught is regulated by two automatic dampers, one for each battery of boilers. The feed-pipes are in duplicate and the steam-pipes practically so, the latter being of solid welded tubes with riveted cast-steel flanges; the main range is 18 inches diameter and has a steam-separator at each end.

The engine-room is 235 feet by 89 feet, and is commanded by two 10-ton travelling-cranes. There are six cross-coupled condensing engines of 800 HP. running at 70 revolutions per minute with a 4-foot stroke; the high-pressure cylinders are 24 inches and the low 48 inches diameter, and all are steam-jacketed.

Three of the engines drive twelve 200-kilowatt Edison generators, four being driven from each engine by means of four 24-inch belts, arranged as a double tandem drive on its flywheel. The other three engines each drive two 300-kilowatt multipolar machines coupled to a pulley by friction-clutches, one 54-inch belt being employed in this case.

The switchboard, which is 62 feet long, 11 feet high and 9 inches thick, stands on a gallery 7 feet above the floor and is in one piece, being composed of terra-cotta lumber, cemented together with adamantine plaster; it is enamelled in front, the edges being finished by a wide moulding of polished cherrywood. Each dynamo is provided with an ammeter, a three-pole switch, a magnetic cut-out and a switch for breaking the field-circuit through a resistance. The rheostats for varying the fields are placed under the gallery, and are worked by shafts passing through the floor opposite the instruments of the machines they respectively control. Each of the twenty-four feeders has an ammeter, a magnetic cut-out and a switch; the system into which they feed is divided into nine sections, each controlled at the station. The voltmeter and main ammeter are Weston instruments and are mounted on a marble panel at right-angles to the switchboard; the same panel supports also a recording voltmeter, a thermometer, barometer and a clock. Two tank lightning-arresters, several magnetic blow-out and Wurts non-arcking arresters, are fixed to guard against damage by lightning. A space 10 feet wide, lighted by several windows, is left behind the switchboard to allow of connections being made at the back with ease. A system of communication between the engines and switchboard is provided by means of which six distinct signals can be sent.

Particulars are given of the overhead conductors and trolley-wires, and of the method of effecting the return. The total length of track is now 74½ miles and is being extended; details are given of the permanent way and of the method of construction adopted. The rolling-stock comprises 180 motor-cars, ninety-five trailers and nine snow-sweepers.

A main repair-shop is provided in a central position and is very completely fitted up, power for the machine-shop being furnished by a motor run from the trolley circuit. An emergency wagon is kept at the shop with men always on duty in readiness for break-

downs. Three car-sheds, with conveniences for ordinary repairs, are erected on the outskirts of the system.

The article concludes with some financial particulars relating to the company.

C. H. W.

Electric Tramway in Lemberg.

(Zeitschrift für Transportwesen und Strassenbau, 1894, p. 332.)

On the 31st of May, 1894, the first electric tramway in Austria-Hungary was opened at Lemberg. The tramway connects the centre of the city with its principal suburbs, and has a total length of 10 miles. The gradient conditions are very unfavourable, gradients of 1 in 25 and 1 in 20 occurring often; the steepest gradient is 1 in 14·8, and is several hundred metres in length. The minimum radius is 49 feet, and this is frequently employed. The rails used are of the Phœnix type, weighing 65·5 lbs. per yard; they are bound together by iron tie-bars, 55 inches long, and are laid directly upon a bed of broken stone.

The overhead system has been adopted, the working wires being of hard copper; the transverse wires are fixed either to iron posts, wooden posts, or to brackets in the wall, according to the character of the street. In the central station there are two locomotive boilers, with about 2,368 square feet of heating surface, and two compound steam-engines; each steam-engine furnishes 200 HP., and drives an inner-pole machine of Messrs. Siemens and Halske's well-known type. The primary tension of the current amounts to 500 volts, and the motors on each car develop 25 HP. Sixteen motor-cars have been provided, half of which are constantly in use.

The construction of the tramway was commenced in September, 1893, and in spite of the severity of the winter was completed as stated above, in May, 1894. Messrs. Siemens and Halske, of Vienna, constructed the line and provided all the fittings.

J. A. T.

On the Vaporization of Carbon. By Henri Moissan.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxix. 1894, p. 776.)

The Author finds that although carbon can be distilled in the interior of his electric furnace, it passes from the solid to the gaseous state without melting. Various experiments were made with the view of ascertaining whether two pieces of pure carbon, *e.g.*, a crucible fitted with a stopper, could be welded together at the high temperature attained, but in no case was there the slightest adhesion, although the substance was completely transformed into graphite.

The deposit obtained by the distillation of carbon was found to be invariably graphite, as was also the case with the black film that forms inside a glow-lamp after long use.

The Author concludes that both at ordinary pressures and in vacuo carbon passes from the solid to the gaseous state without fusion, and that by the condensation of the vapour graphite is always produced. But he believes that at high pressures it will be found possible to liquefy the carbon, and that in this case diamonds will be formed on cooling. He compares the behaviour of carbon with that of arsenic.

G. J. B.

On the Constitution of the Electric Arc. By L. Thomas.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxix., 1894, p. 728.)

The Author has studied the electric arc, with the aid of a differentiating spectroscope, using the precautions indicated by Cornu. When the carbons are charged with metallic salts the arc consists of a central portion surrounded by an envelope. In the central portion are found the bodies giving band spectrums, carbides, or vapour of carbon and cyanogen.

Metallic vapours, arising from the dissociation of the salts, circulate in the envelope from the positive to the negative pole. These vapours, after being electrolytically deposited on the negative pole, combine with the oxygen of the air, and escape in the flame.

Photographic records of the experiments were obtained.

G. J. B.

On the Condensation of Electrolysed Gases by Porous Bodies, more especially the Metals of the Platinum Group.

By L. Cailletet and E. Collardeau.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxix., 1894, p. 830.)

Six grams of platinum-sponge were enclosed in each of two silken bags, immersed in dilute sulphuric acid (10 per cent.). Connection was made by platinum wires with a battery, and the current allowed to pass until the metal was saturated with gas. The polarization current obtained on connecting the two electrodes with a galvanometer was more intense, and lasted longer than would have been the case if the same weight of solid metal had been employed. The Authors then tried the effect of strong pressure, with the view of increasing the storage capacity. The results, which were very striking, are represented in graphic form.

At atmospheric pressure the discharge, taken through a resistance of 2 ohms, lasts only about ten seconds, the electromotive

force falling steadily to zero. At higher pressures three periods are noticeable.

(1) The potential difference falls rapidly at first, and then increases slightly for a few seconds.

(2) This is followed by a period of constant intensity, increasing somewhat with the pressure. During this time the electromotive force is about 1 volt.

(3) The potential difference finally diminishes to zero, but the fall is less rapid than during the first stage.

The capacity of such an accumulator increases with the pressure employed. At 580 atmospheres it is 56 ampere-hours per kilogram of platinum sponge.

It was found best to make the negative-pole about three times the weight of the positive-pole, in order that the condensing powers of each for the gas produced within it might be the same. The efficiency of the discharge, if taken immediately, was found to be from 95 per cent. to 98 per cent. Other metals of the same family were experimented upon. Iridium gave results similar to those of platinum. Ruthenium was slightly attacked at the positive pole. Its capacity as an accumulator increased with the pressure, but the electromotive force decreased steadily during the discharge, without signs of a stationary period. Palladium in the sheet has very little storage capacity, oxygen being given off from the positive pole almost immediately. But in the form of sponge it acts better even than platinum.

At ordinary pressures the discharge shows, first a rapid fall, then a slight rise, followed by a constant period. This result is only obtained with platinum under a pressure of 20 atmospheres or more. As the pressure is raised, the capacity of the palladium-cell increases, and is much greater than that of an equal weight of platinum sponge under the same conditions. Thus, at 600 atmospheres, the capacity of a palladium accumulator was 176 ampere-hours per kilogram.

Gold, precipitated from the chloride by sulphur dioxide, forms an accumulator the capacity of which varies with the pressure. It is not, however, so great, and the curve of the discharge is different. Silver, tin, nickel, and cobalt were tried, but there was chemical action at the positive pole. This was also the case with the various forms of carbon. The oxygen given off contains a considerable percentage of carbon dioxide. But none of these substances showed any increase of storage capacity under the influence of pressure.

G. J. B.

Notes on Pyrometers and the Measurement of High Temperatures.

By Ed. Deny.

(Bulletin de la Société Industrielle de Mulhouse, 1894, p. 359.)

In many important manufacturing processes, especially in metallurgy and foundry work, high temperatures are required, and the use of a practical pyrometer is desirable. Sometimes various alloys of copper and zinc, melting at a known temperature, are employed. Thus an alloy of one part zinc and four of copper melts at 1,050° C.; one part zinc and six of copper at 1,130° C., one part zinc and eight of copper at 1,160° C.; the same quantity of zinc and twelve parts of copper at 1,230° C.; and one part zinc and twenty of copper at 1,300° C. Other compounds of metal are also used. But in all, especially in zinc alloys, the composition may not be exactly the same as that of the constituent metals. Hence it is impossible to fix the temperature from their fusing point with accuracy, and they would be speedily abandoned if a suitable pyrometer were available. The difficulty of constructing these instruments is increased by the high temperatures they have to resist. They must be simple and reliable, indicating quickly and accurately the temperature of the furnace, and marking the progress of combustion. These advantages are not easily obtained.

The earliest pyrometers are based upon the phenomena produced by the direct action of heat upon a body. The principle of expansion is shown in mercury thermometers; in metallic pyrometers, which deteriorate rapidly and cease to expand; and in air-pyrometers, which require most delicate handling.

The Wedgwood pyrometer embodies the principle that clay diminishes in volume when heated, but the instrument gives only approximate results. The composition of the clay affects its contraction for the same temperature, and it also shrinks in proportion to the temperature according to an unknown law, contraction being more marked at low than at high temperatures.

The Siemens pyrometer, or calorimeter with double copper walls, contains a given volume of water. A piece of copper previously plunged in the furnace is dropped into it, and the temperature of the furnace obtained from the rise in temperature of the water. This pyrometer is much used in metallurgical workshops, but it requires a quarter of an hour for each determination. It is also subject to variations, because the copper loses in weight, and in time its calorific capacity is altered. If the precise moment of the change were known, a fresh piece of copper might be substituted, but to determine this would require another perfectly reliable pyrometer, the very instrument the want of which is so much felt. A certain quantity of steam is always produced, and heat consequently lost, when the copper is plunged into the water; the calorific capacity of the metal also rises with

the temperature, and in any case the pyrometer can only indicate up to the point of fusion of the copper. Platinum can also be used.

The nitrogen pyrometer made by Messrs. Richard, of Paris, is not perfectly reliable, but it is useful to measure temperatures from 250° C. to 700° C. It consists of a small iron receiver communicating with a temperature dial, and is based on Regnault's principle that the pressure of air at constant volume is doubled for a rise of 273° C. The working method is very simple. The receiver filled with nitrogen is placed in the furnace, the gas expands, and as the pressure increases the rise in temperature is marked by a needle on the dial. Nitrogen is used instead of pure air, because oxygen is absorbed by iron and affects the results. The instrument is carefully calibrated, and a registering apparatus can be added, to trace the diagram of the furnace temperatures.

One of the best instruments known for measuring high temperatures is the Lamy pyrometer, based on the dissociation of carbonate of lime when exposed to great heat, but it only indicates temperatures between 700° C. and 900° C. with accuracy.

The real difficulty in constructing a pyrometer is that no substance will resist the disintegrating action of great heat. Alcohol and mercury are vaporized at a comparatively low temperature, copper, iron, and even platinum ultimately fuse, and when they approach their melting-point their molecular shape undergoes change, their calorific value is no longer the same, and other contributing phenomena render the pyrometer practically useless. Thermo-electric pyrometers are not subject to these fluctuations, because they depend neither on the expansion, nor on the calorific capacity of metal; but they are too delicate to be used except for scientific purposes. They consist of a thermo-electric pile or couple, of two metals soldered together, acting on a sensitive galvanometer. The Le Chatelier couple is formed of two wires, the soldered end being plunged into the medium, the temperature of which has to be determined. One wire is of pure platinum, the other of platinum with 10 per cent. rhodium; for measuring low temperatures the wires are of iron and copper. They are enclosed in a porcelain tube with asbestos joints, filled up with fire clay. The galvanometer is standardized by placing it in boiling water, melted sulphur, sulphate of potassium and other metals. The readings may be made either direct from the dial-plate upon which the index of the galvanometer moves, or from a graduated scale at a certain distance from the instrument, by means of a mirror. These methods are suitable for scientific observation, but for manufacturing work it is desirable to have an automatic registration of the variations in temperature, and an intermittent system has been introduced by Messrs. Ducretet and Lejeune. It consists of a cylindrical drum driven by clockwork, marked by a pen once a minute. The curve thus dotted represents the phenomena taking place better than if a line were traced.

The Author next describes a differential pyrometer with water-

circulation, and gives detailed drawings of it. If a pyrometer were kept at a lower temperature than the medium the heat of which is to be measured, but were exposed to the fluctuations of temperature of the latter, marking its intensity under perfectly constant conditions, one of the main difficulties of a practical pyrometer would be removed. Such an apparatus would not be subjected to the destructive action of intense heat, and, all other conditions being the same, the relative indications obtained would determine, at least approximately, the actual temperature. This is the principle of Mr. de Saintignon's differential pyrometer. It consists of two mercurial thermometers connected by rubber tubes to a bent copper tube. Water from a reservoir circulates round the first thermometer, enters the copper tube in the furnace, and returns round the second thermometer. The difference between the temperature of the hot and cold water is proportioned to the required temperature of the furnace. Mr. de Saintignon has proved experimentally that the amount of heat absorbed by the water is in proportion to the excess of the furnace temperature over that of the water at admission, and that the rise in temperature for a given quantity of water is always in a certain ratio to the heat of the furnace. Even if the temperatures obtained with this instrument were calculated according to an empirical formula, the results would be equally valuable. It is generally not so much the exact temperature of the furnace that a manufacturer is concerned with, but rather to know that it is sufficient for his purpose, and ascertain when it rises or falls within certain limits.

But to make this pyrometer reliable the volume of water must be constant. On leaving the instrument it is therefore passed under a vertical glass tube open above, and closed below by a cock. If the cock be shut off, the water will overflow at the top; if it be slightly opened, the water will rise to any given height in the tube before it escapes through the cock. This point being marked and the cock set, a uniform discharge is obtained so long as the water reaches the mark. If it exceeds or falls short, allowance must be made, since the thermometer will be affected; and the inventor marks the positions on the gauge corresponding to 5 per cent., 10 per cent., or 15 per cent. above or below the normal quantity of water. As the difference between the two temperatures is always proportioned to the quantity of water, either the correction can be made by a simple calculation, or the water brought to its original height. Experiments prove that it is necessary to filter the water, to keep the pipes clean.

Although the temperature of the water is slightly affected by the external temperature in passing from the tube to the thermometer, the loss of heat at a distance of 23 feet from the furnace has been found to be only $\frac{1}{4}$° C. To avoid loss by radiation the rubber tube should be encased in an air-tube. The copper tube should also be isolated, to prevent the external brickwork from affecting its temperature. A scale on the thermometer shows the heat of the water on its return from the furnace, and by a

slight adjustment the actual temperature of the furnace may be read off without calculation. If, for instance, the scale be so arranged that a difference of 1° between the two thermometers of the instrument corresponds to an increase of 25° in the heat of the furnace, each division of the scale should represent 25°. Its zero must mark the temperature of the thermometer showing the heat of the water at admission, and the scale will then give the temperature of the furnace. To make the instrument record the variations automatically a differential register has been added, marking the difference between the temperatures with a pen upon a drum driven by clockwork. This pyrometer is not perfectly accurate, and cannot be relied on to give the exact temperature, because the tubes may get dirty, and the water become slightly cooled or heated outside the furnace. It has, however, been found of great practical value in France, and has been used for years at the Sèvres Porcelain Works, to indicate the temperatures of the furnaces.

To obtain rapid indications of temperature, the telescopic pyrometer of Messrs. Mesuré and Nouel[1] is of great value. Many of these instruments are now in use. Those at the Montluçon workshops are calibrated as follows:—A temperature of 800° C. corresponds to the first bright red ray and to 33° on the dial. The temperature rises and the colour passes through orange and pale yellow to 1,500° C. (brilliant white), 1,700° C. (colourless), being 74° on the dial. Observation of the sun's light gives 84° on the dial. The object of this pyrometer, however, is not so much to determine temperatures as to follow the variations of heat in an incandescent body or furnace, and ascertain when the exact temperature necessary for any operation is reached. The luminous shade diminishes rapidly as the body cools. If it be necessary to withdraw the latter from the furnace, the smaller the body the more rapidly it must be examined. For daily work in forges, rolling mills, foundries, &c., and in the manufacture and testing of electric and incandescent lamps, this pyrometer will be found of much service.

The Author is of opinion that among the pyrometers here described the Le Chatelier thermo-electric couple is the most useful where scientific accuracy is required, and the Saintignon and telescopic pyrometers for practical purposes and approximate determinations of working temperatures.

B. D.

---

[1] Minutes of Proceedings Inst. C.E., vol. c. p. 506, and vol. cii. p. 419.

The Manufacture of Olive Oil in Sicily.

(Die Oel- und Fett-Industrie, 1894, p. 136, No. 19.)

More than one-fifth of the olive oil produced in Italy is made in Sicily, its manufacture being the chief industry in that island. The factories are usually small, employing from ten to twelve men, and are of one storey only. Upon a platform constructed of heavy masonry and about 1 yard high, an edge-runner of stone about 16 cwt. in weight and 1 foot thick, revolves slowly, the motive power being a horse or mule. The olives, which should be perfectly ripe, are thrown by hand under the revolving stone, and when crushed are removed by means of a shovel. The output is about 1 cwt. of olives in half an hour.

The paste of crushed olives is next placed in soft, flat rush bags having a very small opening. About fifteen such bags are placed one above the other, the openings being upwards. Pressure is then applied by means of a strong wooden screw worked by six or eight men. The pressure is at first applied very gently, then gradually increased. The oil runs through a trough into a tub more than half full of water. The coarser impurities are deposited at the bottom of the water, on the surface of which the oil floats. When the bags have been under pressure for about five minutes they are taken out and their contents again emptied under the edge-runner. This operation is repeated three times. The press residues are then heaped up in a dark room to a depth of about 1 foot 4 inches, and allowed to remain for three days, when they heat spontaneously. They are then brought to the press for a fourth and last time. The final residue, which amounts to about 70 per cent. of the weight of the olives, was formerly used for fuel; but much of it is now sent to larger oil-mills, where it is treated a fifth time. The crude oil is removed to a room where the temperature is as near 66° F. as possible. In about a week it loses its turbid appearance, and is then placed in other vessels, in which it is kept until required for sale or use.

Although a few small steam oil-mills have recently been erected in Sicily, the greater bulk of the olive oil produced is made as described.

W. F. R.

Testing Prepared Tar. By C. Lunge.

(Journal für Gasbeleuchtung, 1894, p. 724.)

Prepared tar-products are mixtures of coal-tar pitch with distillates of coal-tar in varying proportions. After the volatile products have been distilled from the tar, the hard pitch remaining in the still is difficult to remove, and its use, in the hard state, is very limited. It may, however, be utilized by adding to the still-

fluid pitch some of the heavy oils, which are of little value for other purposes. According to the quantity and quality of the oils so added, semi-hard or soft pitch, asphalt, varnish for iron, or "prepared tar" can be produced. The latter term was probably at first applied to a preparation for roofing felt, &c., its advantage being that, the volatile constituents having been removed, it was free from smell and not liable to crack in drying. For both the manufacturer and user it is a great advantage for the benzol, phenol, naphthalene and anthracene to be removed without decreasing the usefulness of the prepared tar, especially as, by regulating the quantity of oil added, any required consistency can be obtained. As under the term "prepared tar" many various compounds may be understood, it is desirable, in order to avoid disputes between the manufacturer and purchaser, to define what in each case the composition should be.

In a case in which the Author had to give a professional opinion it appeared that this was not defined, and the following proceedings are now proposed:—

Three samples of prepared tar, of German and Polish origin, were obtained, and these will be referred to as samples A, B and C.

In making such tests, the use to which the tar is to be applied should be borne in mind, and the test should also be simple and rapid. Many of the properties of the tar, such as the quickness in drying, covering capacity, resistance to weather, &c., cannot be easily determined in laboratory experiments, but they at least admit of the uniform composition of different deliveries being ascertained, and of their agreement with a normal sample. As an easy and accurate mode of testing, three points should be determined, namely, the specific gravity, the viscosity and the quantity of volatile matter. For the determination of the specific gravity, it is proposed to use a specific-gravity tube, with a glass stopper having a small groove filed in the side; the tube is filled with the tar to be tested and the stopper inserted, so as to force the superfluous tar through the groove; after weighing, the tar is poured out, and the vessel is cleaned by wiping out with blotting paper and a little oil. Thick tar frequently contains air-bubbles, which can only be separated by continued heating. The operation may also be effected by partially filling the tube with tar and weighing. Let (a) represent the weight of the empty tube, (b) its weight filled with water at 59° F., (c) the weight filled to about two-thirds its height with tar, and (d) the weight when the remainder of the tube is filled with water. The tube, with the stopper removed, is stood for an hour in hot water until all the air bubbles are expelled and weighed after cooling. The required specific gravity of the tar will then be equal to:

$$\frac{c - a}{b + c - (a + d)}.$$

By this means the specific gravity of the tar, sample A, was found

to be 1·1649 at 64·4° F., of sample B, 1·1972 at 73·4° F., and sample C, 1·2424 at 68° F.

With prepared tar, the viscosity is in many cases of much importance; this cannot be determined in the manner usually adopted for oils, &c., and a specially designed hydrometer was used for the purpose, the rate at which the instrument sank in the tar to a fixed point being taken as a measure of the viscosity. The instrument differs from ordinary hydrometers in being made of very stout glass; the body is cylindrical, with a semi-spherical lower end; it is about 4 inches long and 0·8 inch external diameter, and is surmounted by a stem 8·9 inches long and 0·3 inch diameter. On this, 0·6 inch above the conical neck, the specific gravity of 1·400 is marked, and the specific gravity figures are continued upwards to 1·050, which occupies altogether a length of 7·5 inches, the most important part of the scale, up to 1·250, being at a distance of about 3·2 inches from the neck. The instrument is weighted with shot, held in place by sealing-wax, and it weighs about 600 grains. The tar to be tested is put in a cylindrical vessel to such a height that, when the tester is inserted, the vessel is nearly full; the tar is then well mixed and the temperature determined, the cylinder is then stood in cold water until the tar reaches a temperature of 59° F. The tester is then inserted up to the mark 1·250, withdrawn and allowed to drain. A seconds watch is then taken in one hand and the tester in the other. The latter being held so that its lower end touches the surface of the tar, and it is let go when the seconds hand reaches zero. The tester sinks rapidly until the contracted portion is reached, and then goes much slower; when the mark 1·250 is reached the time is observed, the instrument is then taken out and allowed to drain for two or three minutes, after which a second observation is taken. Three or more observations should be made and they should agree to within two or three seconds. The point 1·250 is sufficiently below the specific gravity of a normal prepared tar, so that the hydrometer sinks very slowly at last, and it is found that small differences in the weights of the testers do not materially affect the results. With tar A, at a temperature of 59° F., the sinking of the instrument varied in time between thirty-four and thirty-seven seconds, and at 76° F. the time was from ten to twelve seconds. With tar B at 59° F. the time occupied was from sixty-nine to seventy-two seconds, at 72° F. forty to forty-one seconds, and at 74·3° F. thirty-two to thirty-three seconds. Tar C was barely fluid at ordinary temperatures and could not be satisfactorily tested in this manner, as at 74·3° F. the instrument took several hours to sink to the 1·250 point.

With regard to the volatile constituents, it would probably be sufficient to stipulate that a prepared tar, at a given temperature, should yield a certain quantity of distillates; but there are many practical difficulties in determining this; the boiling-points of some of the constituents are above that of mercury, and any thermometer, even if made of hardened glass, would become incorrect with use.

A preferable plan is to distil 100 grams in a hard glass tubular retort over an open flame, until a determined quantity of the volatile compounds has passed over; the specific gravity of the distillate is then determined, and, after cooling, the retort is broken and the specific gravity and softening point of the pitch ascertained. If the first trial does not yield a normally hard pitch, another test is made, the distillation being continued for a longer or shorter time, as the conditions of the first trial indicate to be necessary. A second, or, at the most, a third, test will give the required result.

The following examples illustrate the operation:—From 100 grams of tar A 50·2 cubic centimetres (3 cubic inches) of oil were distilled of 1·063 specific gravity, or 53·4 per cent. by weight of the tar; the specific gravity of the pitch being 1·2938 at 73·4° F., the pitch having a dull lustre and would not soften in water at 208° F., which proved it to be hard pitch. In a second trial 44 cubic centimetres (2·68 cubic inches) of oil, of specific gravity 1·040, or 45·7 per cent. by weight, were distilled off. The specific gravity of the pitch was 1·2852 at 68° F., and it was difficult to knead at 163° to 167° F.; at 184° F. it was quite soft, and it melted at 208° F., showing it to be somewhat too hard. In a third trial 40 cubic centimetres of oil were distilled off, the specific gravity being 1·041, or equal to 41·6 per cent. by weight of the tar. The remaining pitch had a specific gravity of 1·2704 at 73·4° F.; it was difficult to knead at 122° F., and very soft at 140° F., and was therefore somewhat below medium hard. From this it is concluded that this prepared tar contains about 43·5 per cent. by weight of oil and 56·5 per cent. of fairly hard pitch. Similar particulars are given for tars B and C.

From such tests certain definite conditions may be fixed for estimating the quality of the prepared tar, such as the specific gravity, the viscosity and the quantity of volatile compounds. In most cases, three tests will be found unnecessary, as the specific gravity and the viscosity will suffice for determining the value.

C. G.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1894-95.—Part II.

N.B.—Titles in italics refer to Original Papers, and those selected for printing only are further distinguished by the suffix "(S.)" or "(St.)," the latter denoting Students' Papers. Abstracted Papers are not so indicated.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

PLATE. 1.

: 8.

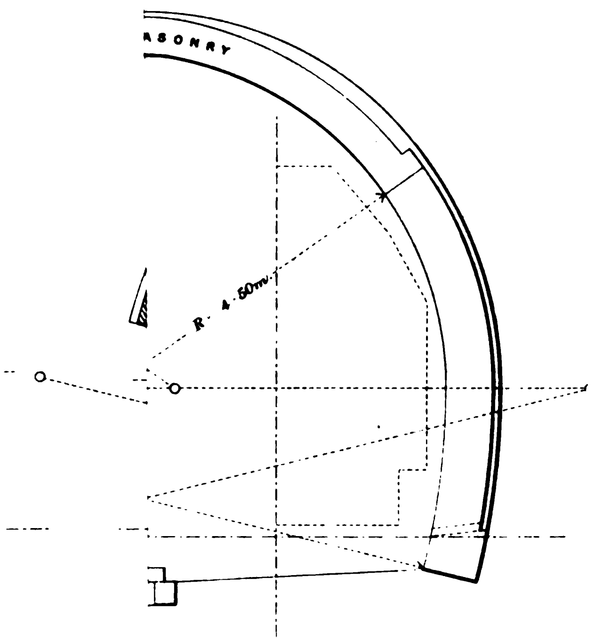
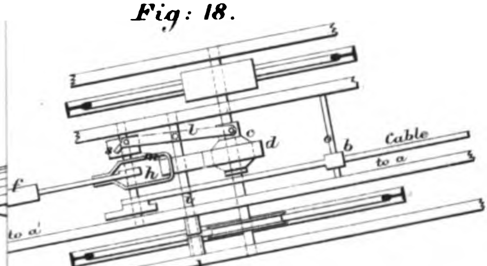


Fig: 18.



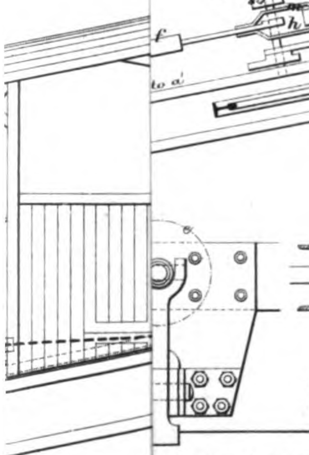


Fig: 20.

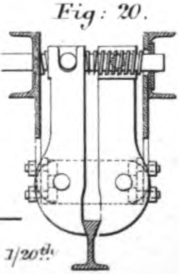
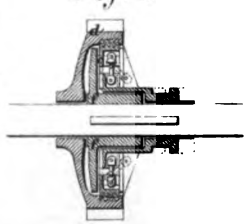


Fig: 21.

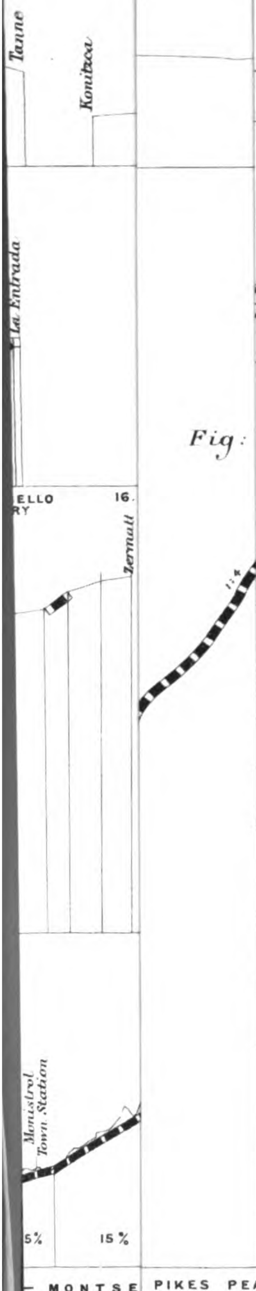


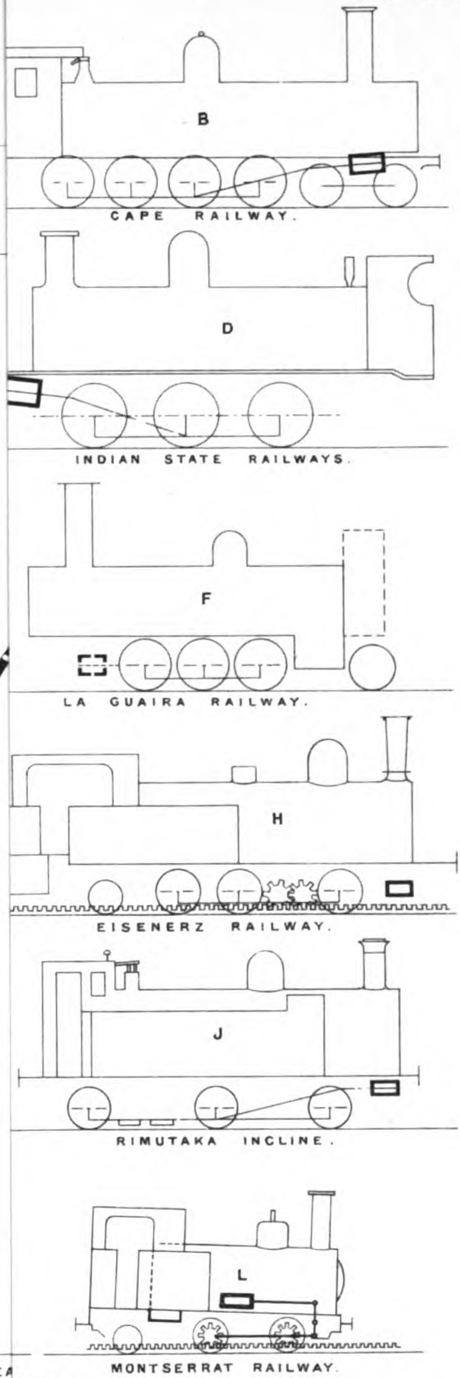
: 19, 20 and 21, 1/20th

Minutes of

THO^S KELL & SON, LITH. 40, KING S^T COVENT GARDEN

PLATE. 2.





4-95. Part. I]

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

Fig: 4

PLATE 3.

Fig: 4.

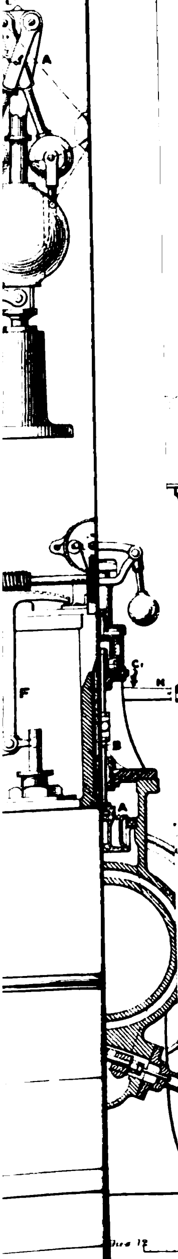
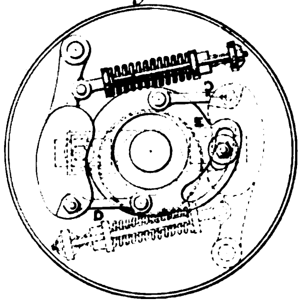
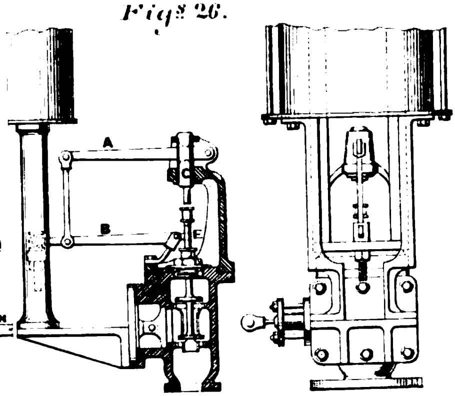


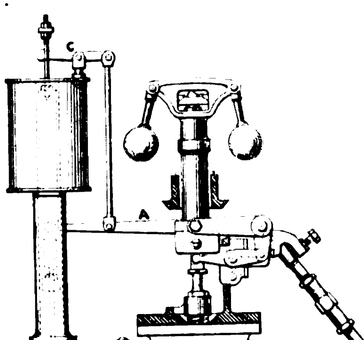
Fig: 15.



Figs 26.



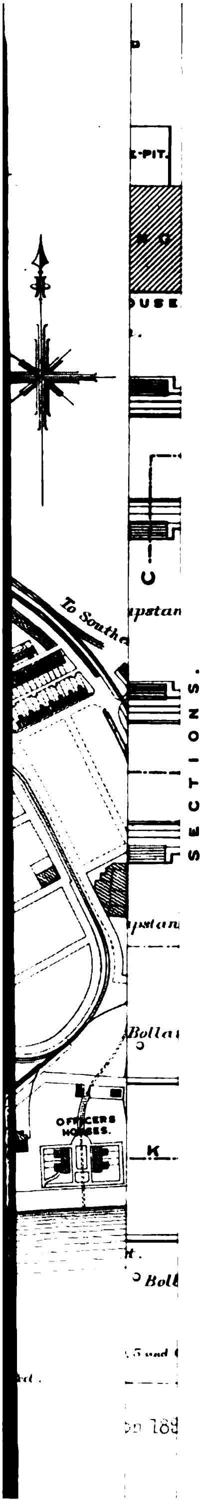
Figs 27.



Feet. 12 Inches.

ssion 18

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.



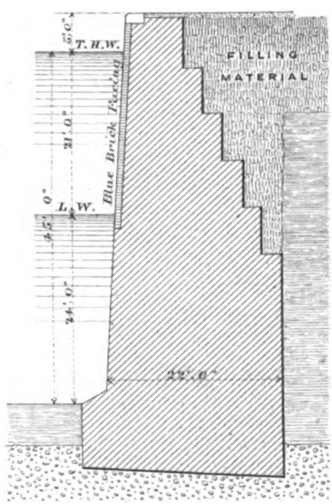
DIMENSIONS.

Lock. Length between gates		*700 feet.*
„ „	*Width*	*80* „
„	*Depth on sill below T.H.W.*	*44* „
Large Graving Docks. Length		*875* „
„ „	*Width at bottom*	*70* „
„ „	*Depth on sill below T.H.W.*	*35* „
Small Graving Docks. Length		*875* „
„ „	*Width at bottom*	*60* „
„ „	*Depth on sill below T.H.W.*	*30* „

NOTE.

Both Graving-Docks are divided by central caissons, forming Docks of 450'.0" & 400'.0", 500'.0" & 350'.0", or 550'.0" & 300'.0".

Fig: 2.



SECTION OF WALL, TIDAL BASIN.

Scale for Fig: 2.

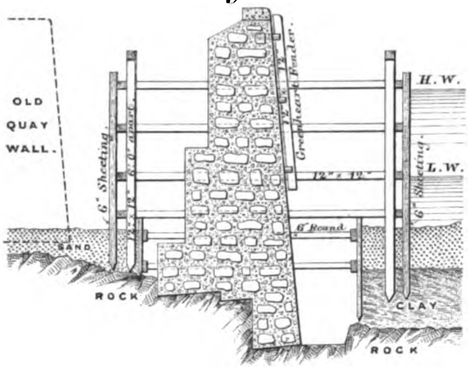
Ft 10 5 0 10 20 30 Ft

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

PLATE 5.

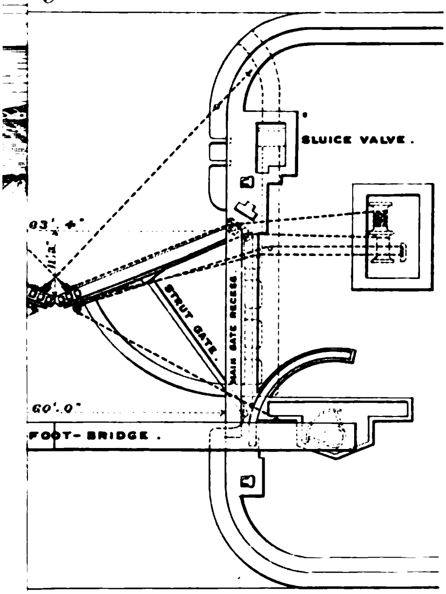
ϽCK.

Fig: 7.



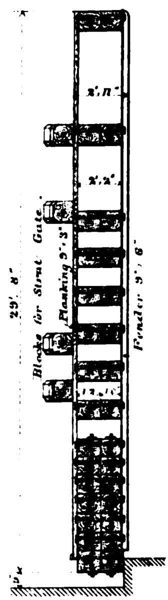
SOUTH AND WEST WALLS, TIDAL BASIN.

ig: 11.



, EGLINTON DOCK.

Fig: 12.

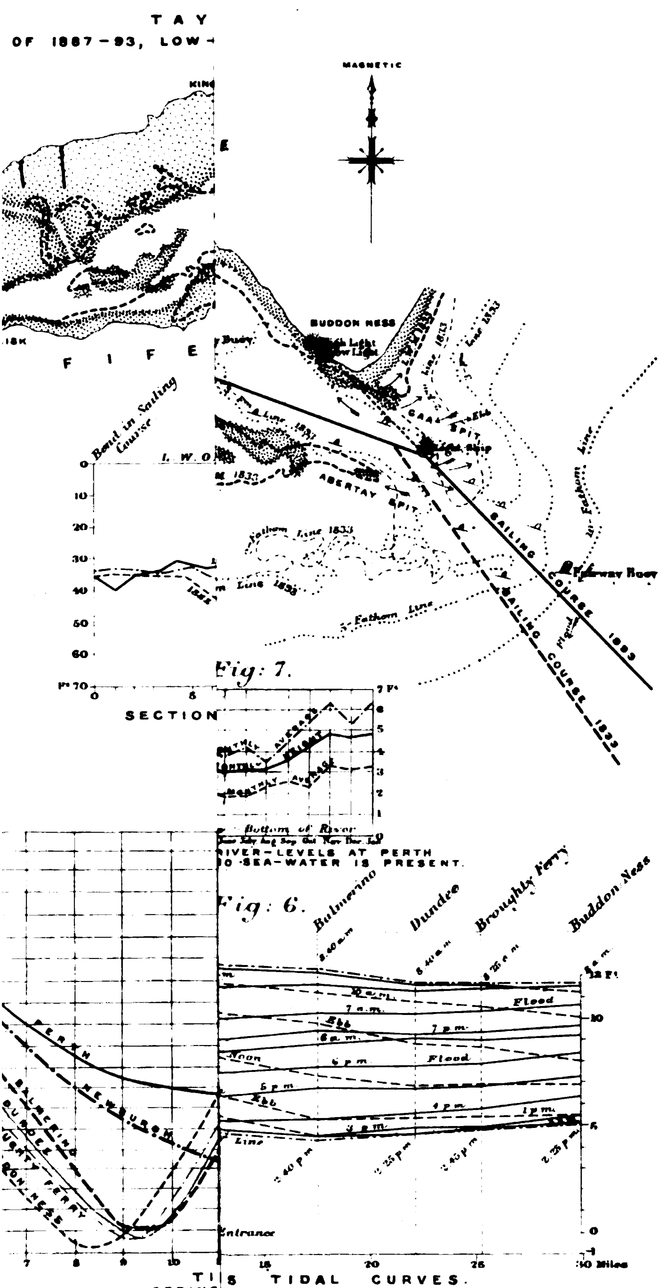


SECTION OF DOCK-GATE.

le to Fig: 12.

Feet 0 10 Feet.

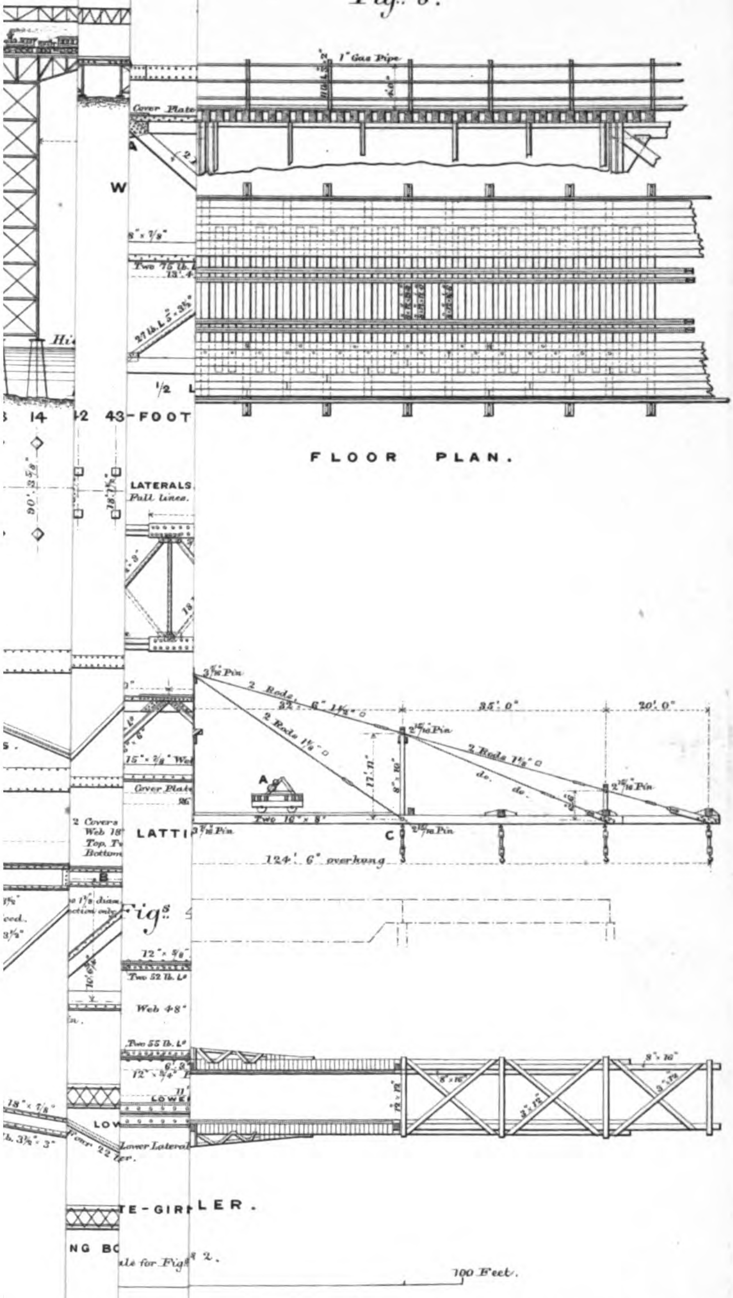
THOS KELL & SON, LITH LONDON.



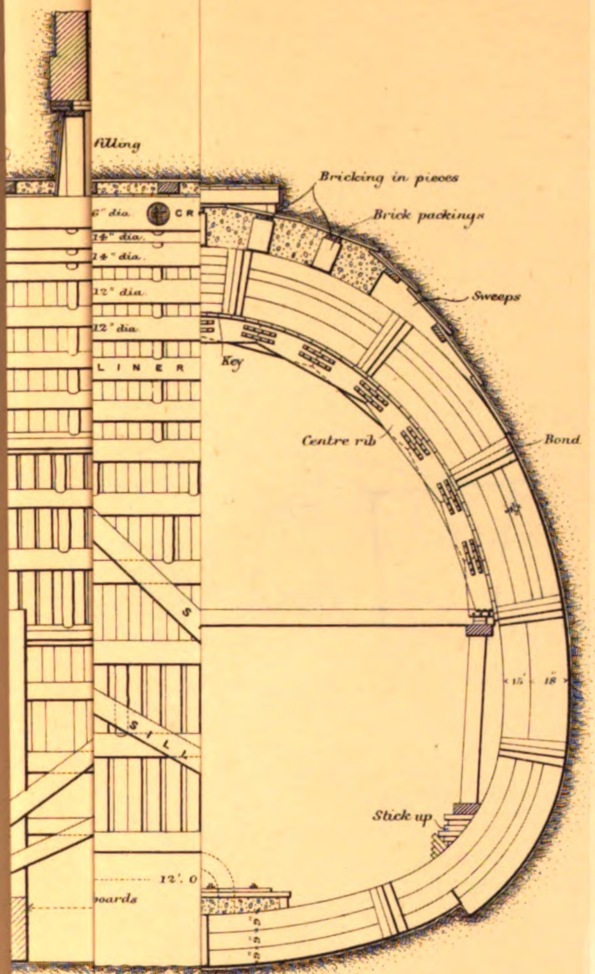
THOS KELL & SON, LITH. LONDON.

PLATE 7.

Figs. 8.



ILL PLATE. 8.



LONGITUDINAL
ERING

HALF—SECTION SHOWING BRICKWORK.

0

e Instit

KELL & SON, LITH. 40, KING ST COVENT GARDEN.